Improving slurry by diet adjustments

A novelty to reduce N losses from grassland based dairy farms

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Abstract

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In order to reduce environmental losses of N, several dairy farmers in the Netherlands aim at a modification of the composition of cow slurry. This deliberate adaptation is one of the crucial elements in a management strategy, characterised by a set of interrelated changes in grassland management and feeding. The basic idea of this strategy is that feeding grass silages with lower protein and higher fibre contents due to restricted use of fertilizer N and a postponed cutting date will result in slurry that is less susceptible to losses of N to the environment through an increase of the $C:N_{total}$ ratio and a decrease of the $N_{inorganic} : N_{total}$ ratio. This modification of dairy cow slurry is regarded as a novelty, i.e. a configuration observed in practice that contains the promise to effectively change established routines. The implementation of the novelty on 60 farms in the nutrient management project of VEL & VANLA indeed resulted in reduced contents of N in roughage, diet and slurry, and a marked decrease of the N surpluses at farm level.

The effect of diet adjustments on the composition of slurry was explored in a controlled experiment with non-lactating cows and through on-farm monitoring. Furthermore, a simulation model was developed to predict the composition of faeces and urine from dietary information. It is shown that the strategy of feeding diets high in fibre and low in protein results in slurry with relatively high $C:N_{total}$ ratio's and low $N_{inorganic} : N_{total}$ ratio's and thus reduced risks for N losses with ammonia. An experiment with slit-injection on grassland revealed that these changes will also result in a reduced first-year plant N availability. From model simulations it was concluded that this reduced N availability will eventually be compensated for by increased soil N mineralization but that this might take decades. Differences in phytotoxicity between slurries were shown in a cress germination test but it was concluded that these differences are not likely to be relevant in established grasslands. Monitoring on twelve farms of the VEL & VANLA project revealed that on average the introduction of the strategy substantially reduced excessive protein feeding, but the data also showed large potential for a further reduction of N excretion per kg milk produced. A theoretical lower boundary of 11.4 g N kg^{-1} FPCM was derived. The success of the feeding strategy in terms of economic and environmental performance appeared to be highly variable. It is concluded that the proposed strategy can be an effective instrument to reduce N excretion and ammonia N losses for farms with predominantly grassland aiming at a moderate production level. To avoid negative performances, the definition of feeding strategies has to be differentiated at individual farm level.

Keywords: Nitrogen losses, Dairy farming, Manure, Nutrient management, Feeding strategies, Novelties, Excretion, Grassland, The Netherlands

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Chapter 1

General Introduction

1.1 Agricultural N in the environment

Nitrogen (N) is an essential element in biochemical pathways. Of the N present in the surface layer of the earth, most is in the non-reactive form (N_2). Less than 2% is in reactive form (oxidised, reduced) and available for organisms (Mackenzie, 1998). For a long time, natural biological N fixation, only carried out by bacteria, was the most important pathway to create reactive N. From 1860 onwards, N has been recognized as the most important nutrient for increasing crop yield in agriculture (Dalton & Brand-Hardy, 2003). In the early 20th century technical advances (industrial N_2 fixation in the Haber-Bosch process) created the opportunity for a large increase in agricultural yields. Post-war industrialisation and the rapidly increasing human and animal population resulted in a strong intensification of agriculture. Besides a doubled global food production (Tilman *et al.*, 2001), the intensification of agriculture has contributed to a rapid increase in the amount of reactive N by the end of the 20th century (Tilman *et al.*, 2001; Galloway *et al.*, 2003).

These enhanced levels of reactive N in the environment lead to several negative environmental effects (Vitousek *et al.*, 1997; Carpenter *et al.*, 1998). Galloway *et al.* (2003) enumerates: the induction of respiratory illness, cancer and cardiac disease in humans related to production of tropospheric ozone and aerosols; a decreased biodiversity in many natural habitats following N deposition; loss of biodiversity in lakes and streams as a result of acidification; hypoxia, loss of biodiversity and habitat degradation in coastal ecosystems related to eutrophication and negative impacts on both human and ecosystem health due to its contribution to global climate change and stratospheric ozone depletion. A large part of these effects have also been observed in the Netherlands (De Vries *et al.*, 2003). Emissions to the atmosphere result in impacts on human health, visibility, crop damage, regional acidification and eutrophication, as well as global warming, while releases to land result in eutrophication of both fresh and coastal waters (Erisman *et al.*, 2003).

In order to reduce the environmental impact of the use of manure and fertilizers in agriculture, several international agreements (Nitrate Directive, Water Framework Directive, NEC-Directive, IPPC-Directives, Air Quality Framework Directive) have been made during the last decades. To comply with these directives and simultaneously maintain productivity requires large efforts from agriculture to increase the efficiency with which nutrients are converted into end-products, certainly for N.

1.2 Pathways of N losses from agricultural systems

Nitrogen in (agro)-ecosystems is present in both inorganic forms and as a part of organic compounds. Inorganic N compounds are incorporated in organic compounds during plant growth and by soil biota. Animals and soil biota convert these organic compounds into inorganic forms again. Primary production in natural ecosystems is highly dependent on such cycling of N and other nutrients (Delwiche, 1970). To current agricultural cycles, additional N is imported through inorganic fertilizer, feed, organic manures and bedding material, and through atmospheric deposition and fixation by legumes (Schröder *et al.*, 2006).

N can be lost to the environment via numerous pathways. One of these pathways is the volatilization of ammonia (NH_3). NH_3 emits mainly from animal excreta, but also from mineral fertilizer and growing crops (Sommer *et al.*, 2004) and decomposing plant material (Whitehead, 1995) NH_3 can be emitted to the atmosphere. Largest sources of NH_3 losses occur from excreta during housing, storage and grazing and after spreading (Jarvis & Pain, 1990; Bussink & Oenema, 1998). Nitrous oxide (N_2O), nitric oxide (NO_x) and elementary N_2 are lost from the soil to the atmosphere through a combination of the microbial processes of denitrification, nitrification and chemo-denitrification (Oenema *et al.*, 2005). Denitrification losses occur also from manure heaps, urine and dung patches (Velthof & Oenema, 1997). N can also be lost from the soil through leaching into the soil profile (entering streams and groundwater), mainly as nitrate (NO_3^-). Leaching occurs when soluble nitrate is present in soil during periods when the soil is at field capacity and receives more water than is needed for evapotranspiration or through soil cracks. Soil nitrate is derived from the direct application with fertilizer, the nitrification of ammonium from slurry or fertilizer and from soil mineralization (Whitehead, 1995). Finally, when the intensity of rainfall or melting snow exceeds the capacity of infiltration, N deposited in excreta or applied with slurry or fertilizer can be lost through runoff (Whitehead, 1995). Runoff is most likely to occur on sloping, frozen or poorly drained soils. Most surface runoff N is in the form of ammonium and ends up in ditches or streams.

N that is neither fixed in animal or plant end-products nor lost to the environment is captured in the soil. N accumulation in the soil indicates that the average N input has been greater than the annual output through crop removal or losses from the soil (Whitehead, 1995). Organic N accumulated in the soil can become available for plant growth in later years as a result of mineralization (Hassink, 1994). When this increased soil N mineralization on grassland is not accompanied by a reduction of the total N input, it gives rise to increased N losses (Cuttle & Scholefield, 1995). In most grassland soils, N accumulation exceeds mineralization while in many arable soils the opposite is valid. After establishment of new grasslands, organic N accumulates asymptotically (with rates up to 170 kg N ha^{-1} $year^{-1}$, Cuttle & Scholefield, 1995) until equilibrium levels have been established. Estimates of time required for reaching this equilibrium after arable cropping range from 50 to 200 years (Whitehead, 1995) and the input of C rather than N is the factor most limiting organic matter and N accumulation below grassland (Ryden, 1984).

1.3 Development of legislation and N surpluses in Dutch dairy farming

Intensification of Dutch agriculture was based on the use of large amounts of external inputs, especially artificial fertilizer and concentrates. The import of external nutrients resulted in a surplus (import of concentrates and fertilizers minus production of milk and meat) of more than 700 million kg N year^{-1} for the entire Dutch agriculture in the late 1980s, with dairy farming as the primary source (Van Keulen *et al.*, 1996). For the Dutch dairy farming sector in the period 1950–1985 the external inputs with concentrates increased from 8 to 153 million kg N year^{-1} and with fertilizer from 70 to 379 million kg N year^{-1}. In the same period, the output in milk and meat also increased, but only from 36 to 83 million kg N year^{-1} (Ketelaars & Van der Ven, 1992). These figures imply that the N surplus (import of concentrates and fertilizers minus production with milk and meat) of the Dutch dairy farming sector increased with a factor 11 in this period from 40 to 450 million kg N year^{-1}. As a result, the efficiency of N conversion of the dairy sector as a whole (production of milk and meat / import of fertilizers and concentrates) decreased by a factor 3, from approximately 46% in the 1950s to only 16% in the mid 1980s. In 1985 the average N surplus of specialized dairy farms was approximately 400 kg N ha^{-1} year^{-1} (Hubeek & De Hoop, 2004).

From the early 1980s onwards the negative environmental consequences of large nutrient surpluses became recognised in both scientific and political circles and since this time the Dutch government has introduced a gradual tightening of policies to reduce these surpluses (Oenema *et al.*, 1998). Characteristic for the first phase (1984–1990) of these policies were the introduction of manure quotas per farm and P based limits for manure application to land (Oenema, 2004). In this period the average N surplus on specialised dairy farms decreased to just above 300 kg N ha^{-1} year^{-1} in the early nineties (Hubeek & De Hoop, 2004). This reduction was mainly caused by a reduction in the use of artificial fertilizers, indicating an increased awareness of the environmental problems associated with a too liberal use of fertilizers (Van der Meer, 2002).

In the second phase (1991–1997), Dutch policies focused on a gradual decrease of manure production, a ban on manure application in autumn and winter and mandatory guidelines to reduce the emission losses of N during storage, handling and application of manure (Oenema, 2004). In 1991, the EU Nitrate Directive was implemented which had the objective to reduce water pollution caused or induced by nitrates from agricultural sources and a preventing of further such pollution (European Community, 1991). Core of this directive was that a balance should be reached between N supply and N demand of the crop where supply includes both animal manure and chemical fertilizer (Henkens & Van Keulen, 2001). However, it was mainly effectuated by an application threshold of 170 kg manure-N ha^{-1} year^{-1}, reflecting the negative relationship between animal density and water quality on a European scale. Complying with this threshold would imply a large reduction of the intensity (and thus the number of cattle and productivity) for Dutch dairy farming. In the early 1990s the average N surplus of specialised dairy farms more or less stabilised just above 300 kg N ha^{-1} year^{-1} in 1997 (Hubeek & De Hoop, 2004) but with a considerable range (220 to 440 kg N ha^{-1} year^{-1}) between specific groups of dairy farms (Reijneveld *et al.*, 2000). In this period, groundwater nitrate concentrations under dairy farms on sandy soils largely exceeded the target value (50 mg l^{-1}) of the Nitrate Directive (Oenema *et al.*, 1998).

To create enforceable and realistic measures that would comply with the objectives of the Nitrate Directive, the Dutch government introduced the Mineral Accounting System (MINAS) in 1998. MINAS was an obligatory system under which farmers had to account for the inputs and outputs of nutrients and calculate the surpluses on an annual basis (Van den Brandt & Smit, 1998; Henkens & Van Keulen, 2001). Increased pressure from the European Community, led the Dutch government to shorten the target period for reducing surpluses from 2008 to 2003 (Henkens & Van Keulen, 2001). As a consequence, from 2003 onwards farms had to meet targets for N surpluses of 100 and 180 kg ha^{-1} year^{-1} for arable land and grassland respectively, which required an average reduction of the farm gate N surplus by a factor two compared to 1997.

Though direct environmental losses are not measured by MINAS, the introduction of the MINAS system necessitated adjustments in farm management practices, which were at that time still largely based on a tradition of high input agriculture. By the late nineties, nationwide and regional nutrient management projects emerged (e.g. Oenema *et al.*, 2001; Ondersteijn *et al.*, 2002; Chapter 2 of this thesis) to assist farmers in the transition to farming with reduced nutrient inputs. All these projects showed considerable progress in reducing N surpluses (e.g. Chapter 2 in this thesis, Doornewaard *et al.*, 2002; Oenema & Aarts, 2005). In retrospect, the introduction of the MINAS system and the efforts made in that period definitely paid off in terms of N surplus as nationwide average N surpluses for specialised dairy farms have reduced from approximately 300 kg N ha^{-1} year^{-1} in 1997 to approximately 200 kg N ha^{-1} year^{-1} in 2001 (Hubeek & De Hoop, 2004).

After a 4-year procedure, European Court rejected MINAS in 2003 as a valid instrument for implementation of the Nitrate Directive. Main reasons for this decision were that 1) MINAS permitted a rate of manure N application substantial higher than 170 kg ha^{-1} year^{-1}; 2) regulatory levies were not prohibitive, and 3) that there was an imbalance between expected N demand from the crops and N supply as soil accumulation, mineralization, deposition and biological fixation were not taken into account in the permitted surpluses (Henkens & Van Keulen, 2001). From 2006 onwards the MINAS system has been replaced with a system based on N and P application standards, differentiated by soil and crop type. In this system, the use of animal manure has to be restricted to 170 kg N ha^{-1} year^{-1}, replenished with inorganic fertilizer to the value of the application standards.

As a result of the favourable climatic conditions, grassland production in the Netherlands is high compared to most other European member states. Schröder *et al.* (2005) concluded that the N demand of cut grassland in the Netherlands can be satisfied by cattle manure at rates of 330–340 kg manure N per ha per year without exceeding the target value set in the Nitrate Directive (50 mg NO_3^- l^{-1}). On the basis of this study, the commission of the European Community granted the Netherlands derogation. This derogation is valid for the period 2006–2009 and allows farms with at least 70% grassland, under certain conditions[1], to apply livestock manure up to a total of 250 kg ha^{-1} $year^{-1}$ (European Community, 2005). To maintain its intensity, prolongation of this derogation is crucial for Dutch dairy farming.

Besides legislation on the protection of water and soil, separate legislation on the abatement of ammonia emission has been implemented in the Netherlands (Starmans & Van der Hoek, 2007). Since 1993, farmers and the industry were financially encouraged to develop low emission housing systems on a voluntary basis. This has resulted in an acceleration of low emission housing systems in pig and poultry husbandry whereas in the dairy farming sector only few technical solutions were implemented. In 2002, the Dutch Farmers Union came to an agreement with the government that dairy farmers were safeguarded from the investment in low emission housing systems in exchange for a reduction of the milk urea content to an average value of 20 mg urea per 100 ml in 2010 (Aarnink *et al.*, 2007). In this agreement it is assumed that a reduction in milk urea content will result in a reduction of ammonia and total N emission. Irrespective of the reliability of these relations (Tamminga *et al.*, 2004), this agreement indicates that Dutch dairy farmers have commited themselves to improved nutrition management with respect to N.

1.4 The role of nutrition management in the reduction of N surpluses

The production process of milk on a dairy farm can be considered as a continuous recycling of nutrients. Feed N is converted into milk, meat and manure and this manure N is converted through the soil into feed again. Each transfer of N provides a risk for losses as described in Section 1.2. Nutrient management strategies should be focused on the avoidance of these losses throughout the system to improve the efficiency of internal N cycling. From the late 1980s onwards, much technical research aimed at the reduction of N losses from dairy farming, has been carried out with contributions of various

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[1] These conditions include the establishments of fertilizer plans on a farm by farm basis, the recording of fertilizer practices through fertilizer accounts, periodical soil analysis, obligatory use of cover crops after maize production, no manure application before grassland ploughing and adjustment of fertilization to take into account the contribution of leguminous crops. Furthermore, total manure production may not increase compared to 2002 and the effects of derogation on water quality have to be monitored extensively.

scientific disciplines (Van der Meer *et al.*, 1991). During the 1990s it was recognised that considerable reductions of the environmental impact of farming without drastic reductions in productivity required a more systemic approach at farm level (Aarts *et al.*, 1992; Jarvis *et al.*, 1996). The adjustments required to improve N efficiency at farm level have been explored in modelling studies (e.g. Kohn *et al.*, 1997; Rotz *et al.*, 1999) and on experimental farms. The experimental farm 'De Marke' (Aarts, 2000) and 'Minderhoudhoeve' (Oomen *et al.*, 1998) showed that N surpluses could be strongly reduced without hampering productivity through a proper nutrient management. Later on, Ondersteijn *et al.* (2003a) concluded from the analysis of a large empirical dataset that farm management (grazing, feeding, fertilization) explained a much larger part of the variation in N surpluses than farm structure (size, intensity, milk production capacity) and that a reduction of N surpluses was significantly related to an improvement of financial performance, indicating the strong potential of improved nutrient management.

Cow nutrition has been identified as an important element of nutrient management (Tamminga, 1992; Valk, 2002). By balancing the supply of nutrients to the needs of the animal, the conversion efficiency of nutrients can be substantially improved. At cow level, the maximum conversion efficiency of ingested N into milk N is 40–45% (Van Vuuren & Meijs, 1987). At farm level the maximum N conversion efficiency of a dairy herd (including young stock and dry cows) is limited to approximately 25% (Aarts *et al.*, 1992, Børsting *et al.*, 2003). The typical feed N conversion efficiencies of dairy herds fed with heavily fertilized grass in the late 1980s were estimated as low as 15% (Aarts *et al.*, 1992; Van Bruchem *et al.*, 1999a). Compared to that situation, the amount of N excreted in manure (faeces and urine) per kg milk produced can be strongly reduced by proper feeding management (Castillo *et al.*, 2000; Kebreab *et al.*, 2002; Børsting *et al.*, 2003). However, at least 75% of the N ingested by the herd is excreted with manure. This implies that the main part of the N cycling on a dairy farm is internal exchange between herd and fields in the form of manure and home-grown feed (Børsting *et al.*, 2003). Therefore, an efficient utilization of the N contained in manure is the key issue in the reduction of N losses from the dairy farm.

Changes in nutrition management not only affect the amount of excreted N. Apart from the reduced total N excreta production, a more than proportional reduction of the urinary N excretion will be established when better balanced diets are fed (Van Vuuren *et al.*, 1993; Kebreab *et al.*, 2002) which is expected to have a strong reducing effect on total N losses with ammonia (Bussink & Oenema, 1998). In the Netherlands, faeces and urine are generally stored in a mixed slurry system. It has been shown that changes in nutrition management also affect the composition of slurry, its characteristics when used as an organic fertilizer and the N losses occurring during storage and soil application (Paul *et al.*, 1998; Külling *et al.*, 2001; Sørensen *et al.*, 2003). Therefore, nutrition management is not only interesting as a means to reduce the total production of manure

N but it also affects almost every process on the dairy farm where N is converted and lost.

1.5 The socio-technical regime of Dutch dairy farming

The large increase of N surpluses in Dutch dairy farming in the second half of the 20th century was not only a technical issue but also connected with socio-cultural developments. As to speak with Van der Ploeg *et al.* (2004), material issues are intrinsically elements of existing socio-technical regimes.

"A socio-technical regime is the grammar or rule set comprised in the coherent complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems - all of them embedded in institutions and infrastructures" (Rip & Kemp, 1998).

A socio-technical regime specifies the way a societal segment is working, it orders both the 'social' and the 'material', it implies a specific distribution of knowledge (and thus also ignorance) and it links different levels, different actors and different dimensions. The existing regimes in agriculture today stem from the modernisation project that reshaped Europe's agriculture drastically in the 20th century. Before modernisation, farming was largely locally oriented, building on local ecosystems, knowledge, skills, craftsmanship and social and economic relations. Agricultural production involved the co-ordination and fine-tuning of an extensive range of farm-specific growth factors which were constantly regulated, modified, and co-ordinated through the labour process in agriculture. In the end, yield was determined by the most limiting growth factor. At the end of the 19th century hardly any fertilizer was used in Dutch dairy farming and the import of feed was also negligible (Oenema *et al*., 2006).

Two phases can be distinguished in the modernisation trajectory of Dutch agriculture: 1) the introduction of agricultural sciences (from approximately 1890 to 1950) and 2) a strong intensification of agriculture (1950–1990). After the agricultural crisis in the 1880s, Dutch agriculture was considered to lag behind in compared to other European countries (Hofstee, 1963). To increase productivity, the Dutch government promoted the development of agricultural sciences. This was realised through the appointment of agricultural engineers that provided farmers throughout the country with the newest scientific information, mainly by giving lectures (De Boer, 1958; Hofstee, 1963). The available scientific knowledge on animal nutrition rapidly increased (Timmermans, 1922; Leignes Bakhoven, 1938). This period was characterised by an increase of the productivity of Dutch agriculture as a whole (Hofstee, 1963). The number of cattle increased as well as the use of fertilizer but the latter only to a limited extent in that period (Oenema *et al.*, 2006). As indicated in Section 1.3, the national N surplus was still low in 1950.

In this first phase of modernisation, there was a strong interaction between agricultural research and farming practice. Agricultural production was regarded as a local optimization process, i.e. a process of fine-tuning the available resources. As the use of external inputs was limited, the characteristics of farm-specific internal resources (individual fields and cows) were crucial in this process (Textbox 1.1, quotes 4 and 5). A better *utilization* of the produced feed and *optimum* levels of milk production were evidently aspects to strive for. In this optimization process, agricultural sciences were regarded as powerful instruments but its value and implication had to be evaluated at farm level (Textbox 1.1, quotes 2, 4 and 5). Furthermore it was recognized in an early stage that scientific disciplines should not function in isolation (Textbox 1.1, quote 1). A final characteristic of the regime in this period was that a strong intensification of the use of external inputs already at that time was critically addressed and that it was expected to yield negative side-effects with respect to economic performance and the health conditions of the animals (Textbox 1.1, quote 2, 3 and 6).

After the food crisis in the World War II, both the European and the national governments launched large campaigns to secure food production. During this second phase of the modernisation trajectory, agriculture changed in a radical and far reaching way, especially in the Netherlands. Agricultural production increased through scale-enlargement, the input of technology and the unrestricted access to cheap external inputs. The needs for an increased use of fertilizer seems unanimously promoted and regarded as a sign of improvement during this period (Hofstee, 1963). Total milk production and labour productivity of Dutch dairy farms increased strongly. However, through the large-scale input of technology and nutrients (Textbox 1.2, quotes 2, 3 and 6) the need to optimize the production process (that is to seek and correct the limiting growth factors) disappeared. Farm-specific circumstances were overruled by the abundant availability of external resources. As a result, the ‘art of farming’ became increasingly disconnected from farm-specific local resources; farming became a function of generally applicable technologies, inputs and corresponding rules and procedures (Altieri, 1990; Van der Ploeg, 1992).

Textbox 1.1 *Some characteristics quotes of the socio-technical regime on cow nutrition in the first phase of modernisation (1890–1950).*

1) When we practice natural sciences, we split nature into little pieces..... because the capacity of our mind is limited. However, nature as a whole can not be split into pieces. This implies that one discipline is strongly connected to the other and people from different disciplines continuously need each other. ***(Timmermans, 1922)***

2) The goal of animal nutrition is to examine how to obtain the maximum profit of the herd, with own products and the lowest possible feed import.....for the farmer it is not the first objective to get a high milk production, he should rather strive to compose the diet in such a way that the profit is maximized. ***(Leignes Bakhoven, 1938)***

3) Various considerations give rise to the thought that modern pasture techniques result in irrational feeding of dairy cattle.... When the food only consisted of young grass, the N-metabolism was poor, especially in 1939 (the year the grassland fertilization was high). It is considerably improved by replacing half of the grass by potatoes and oatstraw.....Without improvement of diet composition in the summer period, modern pasture techniques have, besides economic, also other drawbacks such as a negative effect on the health of the animals and a negative impact on the consistency of the butter. ***(Sjollema, 1941)***

4) There is probably no feed with a larger variation in feeding values than grass. Feeding values of grass depend on a large number of circumstances such as the type and growth stage of the grass, the weather, the soil type, the groundwater level, the manure that is applied, the way the field is used and treated......when farmers try to get a better insight in these differences (by taking grassland samples), this would be very important to increase the feed production at the farm and to come to a better utilization of the produced feed. ***(Van der Meulen, 1942, pp. 86-87)***

5) For the farmer the economic optimum is evidently decisive. However, he can only go for that optimum when he knows about the physiological optimum and the economic relations. The ***art of farming*** *is to search for the economic optimum within all those relations that condition and specify it. For the physiological optimum, one can give a number or a range that is equal for all cows. The economic optimum has to be found by every farmer himself: it is different for every farm, for every time and even for every cow'.* ***(Van der Meulen, 1942, pp. 137)***

6) An increase of the production will require an intensification of the use of fertilizers. We should ask ourselves what this implies for the supply of macro nutrients to our cattle.... From dressings up to 100-150 kg N ha^{-1} $year^{-1}$ *on grasslands, provided that they are well spread throughout the season, no disadvantages with respect to the protein content are expected.* ***(Lehr, 1951)***

Textbox 1.2: *Some characteristic quotes from the socio-technical regime on cow nutrition in the second phase of modernisation (1950–1990)*

1) It is beyond all doubt that a very large N intake puts a heavy burden on the body of the cow (especially the liver and kidneys). Many researchers have expressed their worries in this respect: it is however the question whether this burden can be considered as acceptable or not.... Very likely the regulating capacity of ruminants is highly underestimated in this respect.... ***(Iwema, 1958)***

2) The goal of animal nutrition is to increase the production of our animals to highest profitable limits while maintaining their health by means of a functional nutrition. ***(Verhoeven & Van der Ban, 1965)***

3) Though the discussion on the need for forage is definitely not closed, we may assume that a minimum of 30% forage in the diet is necessary to keep the digestive tract healthy. High producing dairy cows need, besides grass silage from moderate quality, extra intake of concentrates. The question remains whether these animals may have ad libitum access to concentrates and forages. At the moment, ad libitum access seems attractive, provided that the herd is highly productive. ***(Heida & Nijenhuis, 1975)***

*4) In fact a 'feed extraction plan' is, together with a 'grazing plan' and a 'fertilization plan' an element of the 'pasture use plan'. A 'pasture use plan' is on its turn an element of a complete 'firm plan'. That is where economics, forage science and animal nutrition come together. The question is whether this integration is always optimal.... 'economics' and 'forage science' use different values for grass intakes in the grazing period and the question is which of these values holds. (***Heida & Nijenhuis, 1975)***

5) Through increase in scale and the accompanying intensification (more cows per ha) the earlier situation of 8-12 kg forage per cow per day is outdated. Farms with a forage intake of 7-9 kg are no longer an exception. This requires a lot of attention for the rationing of forage. Through the increase of the production level, many cows produce more than 30 kg per day. This requires higher levels of energy and protein and thus an increase of the concentrate use. ***(Osinga, 1978)***

6) Nitrogen is important for dairy farms. It is a nutrient that increases grassland yield more than any other nutrient. Some farms use more than 500 kg N. This is more than the Research Station for Cattle Husbandry considers optimal, e.g. 400 kg N on sand and clay and 250 kg on moisture-holding peat soils. On wet peat soils also 400 kg N can be applied. Economic studies show the advantages of a high N use, especially for small farms. Bearing the preceding in mind, as well as increasing prices for energy and changing price ratio's between feed and fertilizer, linear programming was applied with the following objectives:

- *What is, under the present circumstances, the optimal N application rate on grassland?*
- *Is this rate affected by the price of fertilizer N, the price ratio between milk and concentrates, the size of the farm, the production or purchase of maize silage and the production level per cow?* ***(Wieling, 1981)***

The regime in this period heavily relied on agricultural research and extension. Agricultural research was expected to provide answers with general validity (e.g. Textbox 1.2, quote 3 and 4) rather than insights farmers can use to base management decisions upon in their specific situation (e.g. Textbox 1.1, quote 5). This search for generally applicable rules is tellingly illustrated by quote 6 (Textbox 1.2) where the author is searching for 'the optimal dairy farm' and quote 3 (Textbox 1.2) where the authors would like to terminate the discussion on the variation in grass intake of grazing dairy cows by finding one appropriate value. No need was felt to involve farmers in research formulation as it was generally accepted that the focus of research was to find means to increase productivity (Textbox 1.2). This resulted not only in a reduced interaction between agricultural research and farming practice but also in a stronger fragmentation of the agricultural sciences as the need to integrate disciplines was mainly addressed at the level of the farm (Textbox 1.2, quote 4).

The regime constructed during this second phase of the modernisation trajectory (1950–1990) imposed prescriptions of farming practices and regulations and targets that tended to be generic, regardless of farm-specific circumstances and which were legitimised by claims on scientific grounding (Van der Ploeg *et al.*, 2004). On the one hand, this regime has resulted in considerable progress in food security and agricultural yields, but on the other it has led to the environmental problems agriculture is facing today. Generally, socio-technical regimes are stable and inert as they form a strongly attuned coherent whole. As a result, radical technical changes are difficult to realize (Geels & Kemp, 2000). Following this theory, radical changes in nutrient surpluses of dairy farms are hampered by the existing socio-technical regime. Tackling the problem of N surpluses requires not only a range of adaptations at the individual farm level but also a shift of this institutionalised socio-technical regime as a whole. Especially the focus on generic rules, the ignorance of the importance of farm-specific circumstances in farm management decisions and the reduced interaction between research and farming practice are aspects that potentially block technical changes[2].

1.6 Improving slurry composition as a novelty

Summarizing the introducing sections described above: N surpluses from Dutch dairy farming can be strongly reduced by an improvement of nutrient management with cow nutrition as a crucial element. This improved nutrient management requires a well-articulated reduction of external inputs in such a way that the actual losses to the environment are minimized and the economic performance and productivity of the farm

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[2] Other relevant elements of the regime constructed during this period are the enormous economic interests of the concentrate and fertilizer industry and the distrust that has been created between farmers and the government by first promoting the use of external inputs and than driving it back again.

is maintained. This requires an optimization process in which all relevant elements of the farming system and its interrelations have to be re-organised (Van Bruchem *et al.*, 1999a). Van der Ploeg *et al.* (2004) refer to this process as a process of integrated downgrading. In contrast to the time when access to external inputs was nearly unrestricted, the characteristics of farm-specific growth factors become relevant again. Specific soils, specific crops, specific animals, specific weather conditions require specific strategies to avoid nutrient losses. Furthermore, all farmers have their own way of ordering the production process partly based on personal preferences and capabilities. To a certain extent, a successful reduction of N surpluses asks for a re-invention of the 'art of farming' (Van der Meulen, 1942).

At the end of the 20th century, most research was intended to fill in remaining gaps in the available scientific knowledge constructed during the modernisation regime. This type of research alone is probably insufficient to provoke the desired management changes as these changes require a new attitude, a certain break with the existing regime and its routines. Such a break with the existing routines can be described as a novelty: that is a new configuration that promises to work (Rip & Kemp, 1998). Novelties are, in one or more ways, at odds with the existing regime and often emerge from its 'periphery'. In contrast to innovations, that represent the next step forward along predefined lines, novelties entail the possibility of a regime shift. Throughout agricultural history, emerging novelties have been explored, nurtured, unpacked, tested and improved by extension services and individual agricultural scientists (Van der Ploeg *et al.*, 2004). This thesis deals with such a novelty; that is:

The idea that the composition of slurry can be modified by means of diet adjustments and that this modification contributes to reduced N losses from grassland-based dairy farms.

This deliberate adaptation of cow slurry composition is one of the crucial elements of an integrated downgrading strategy, applied and promoted by several groups of dairy farmers in the Netherlands during the last decade. This strategy is characterised by a set of interrelated changes in grassland management and feeding. Its basic idea is to adjust grass silage and diet composition towards lower protein and higher fibre contents. It is anticipated that the proposed adjustments in diet and manure will result in slurry that is less susceptible to losses of N to the environment. In this thesis, cattle slurry composition and the way it is influenced by nutrition management are the central issues. The described novelty will be evaluated at various levels, from various disciplinary angles and by using a variety of scientific methods in order to assess its potential contribution to the reduction of N losses from Dutch dairy farming.

1.7 Overview of this thesis

All chapters can be read separately and have a different focus on the described novelty of adjusting cattle slurry. Chapter 2 was published in 2004 and describes the on-farm nutrient management project of two environmental co-operatives (VEL & VANLA) located in the northern Friesian Woodlands in the Netherlands. In this nutrient management the described novelty was actively promoted and adopted. This chapter describes how the novelty was addressed and implemented on practical dairy farms during the period 1998–2003, its backgrounds and practical outcomes. Chapter 3 was published in 2003 and describes the results of a pilot study with four cattle slurries originating from farms with different feeding strategies. This chapter explores several slurry quality aspects which were expected to be affected by changes in cow nutrition.

Chapter 4 was published in 2007 and deals with the effects of differences in diet composition on N availability from cattle slurries when applied to grassland, both in the short and long term. Cattle slurries with a wide variation in chemical composition, obtained by feeding a large range of diets were tested in a one-year experiment and evaluated using model simulation. In Chapter 5, submitted to a scientific journal in 2007, a simulation model is presented to predict the composition of dairy cow excreta and subsequent slurry from the composition of the diet, based on a dynamic rumen fermentation model. With this model, forty nutritional strategies for dairy cows, including the adjustments proposed in the described strategy, were explored and the impact of these strategies on slurry composition, slurry N availability and ammonia N losses are discussed.

Chapter 6, submitted to a scientific journal in 2007, describes the results of on-farm monitoring of diet and slurry composition on 12 dairy farms in the VEL & VANLA project in three subsequent winter periods (2001–2004). This chapter focuses on the variation in and relation between diet and slurry composition and how this relates with the environmental, productive and economic performance of these farms. Finally, Chapter 7 contains a general discussion that evaluates the process of studying a novelty; the potential of the described novelty and some remarks on a further reduction of N losses from Dutch dairy farming.

Chapter 2

The nutrient management project of environmental co-operatives VEL and VANLA as a starting point

Based on:

J.W. Reijs, F.P.M. Verhoeven, J. Van Bruchem, J.D. Van der Ploeg & E.A. Lantinga

The nutrient management project of the VEL and VANLA environmental co-operatives

In: J.S.C. Wiskerke & J.D. Van der Ploeg (Eds.): Seeds of Transition: Essays on novelty production, niches and regimes in agriculture, 149–183.

Abstract

This chapter describes the on-farm nutrient management project of two environmental co-operatives (VEL and VANLA) that has been running from 1997 to 2003 and has been functioning as starting point for this thesis. The project aimed at a reduction of N surpluses and was focused on changes in management style, adapted to local conditions and oriented towards an overall re-balancing and downgrading of external resources. Key elements of the project were 1) a holistic and systematic approach on N flows at the farm level, 2) the use of a typical feeding strategy in order to reduce excessive N flow throughout the system and 3) the combination of scientific and experiential knowledge to create a joint learning process, stimulating the farmers to implement new strategies. The major part of the participating farmers, succeeded in reducing the farm level N surpluses, mainly through a reduction of fertiliser input. It is shown that this reduction is reflected in changes in the composition of the diet, roughage and manure without adverse effects on productivity. It is argued that a strong reduction of N surpluses at the farm level is well-feasible but asks for an integrated and active re-balancing process of the whole farming system. Running at lower levels of external inputs, dependency on farm-specific resources increases. This implies that the management and skills of the farmer and their knowledge about specific, locally available resources are becoming more important. This new situation requires a greater contextualisation of research and advice services.

2.1 Introduction to the nutrient management project

This chapter describes the on-farm nutrient management project of the VEL and VANLA environmental co-operatives that has been running from 1997 to 2003 and has been functioning as starting point for this thesis. Figure 2.1 provides a schematic overview of the development of the project, which has its roots in a heterogeneous set of farming practices (A in figure 2.1) that already existed in the area. Throughout the 80s and 90s, farmers in the area were subject to a newly emerging set of regulations (B in figure 2.1). The effects of these were twofold: on the one hand several regulations were at odds with the practices employed on the small-scale farms in the area (sometimes prohibiting them outright); on the other hand farmers became increasingly interested in the particularities of their own ways of farming.

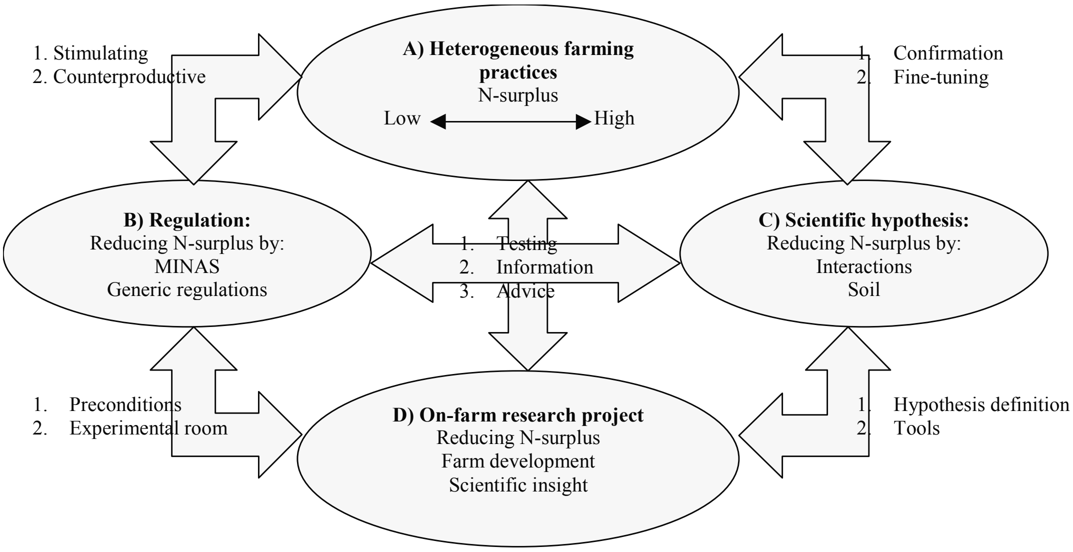


Figure 2.1 *Schematic overview of the relation between farming practices, a scientific hypothesis, environmental regulation and the on-farm research project at the start of the nutrient management project of the environmental co-operatives of VEL & VANLA*

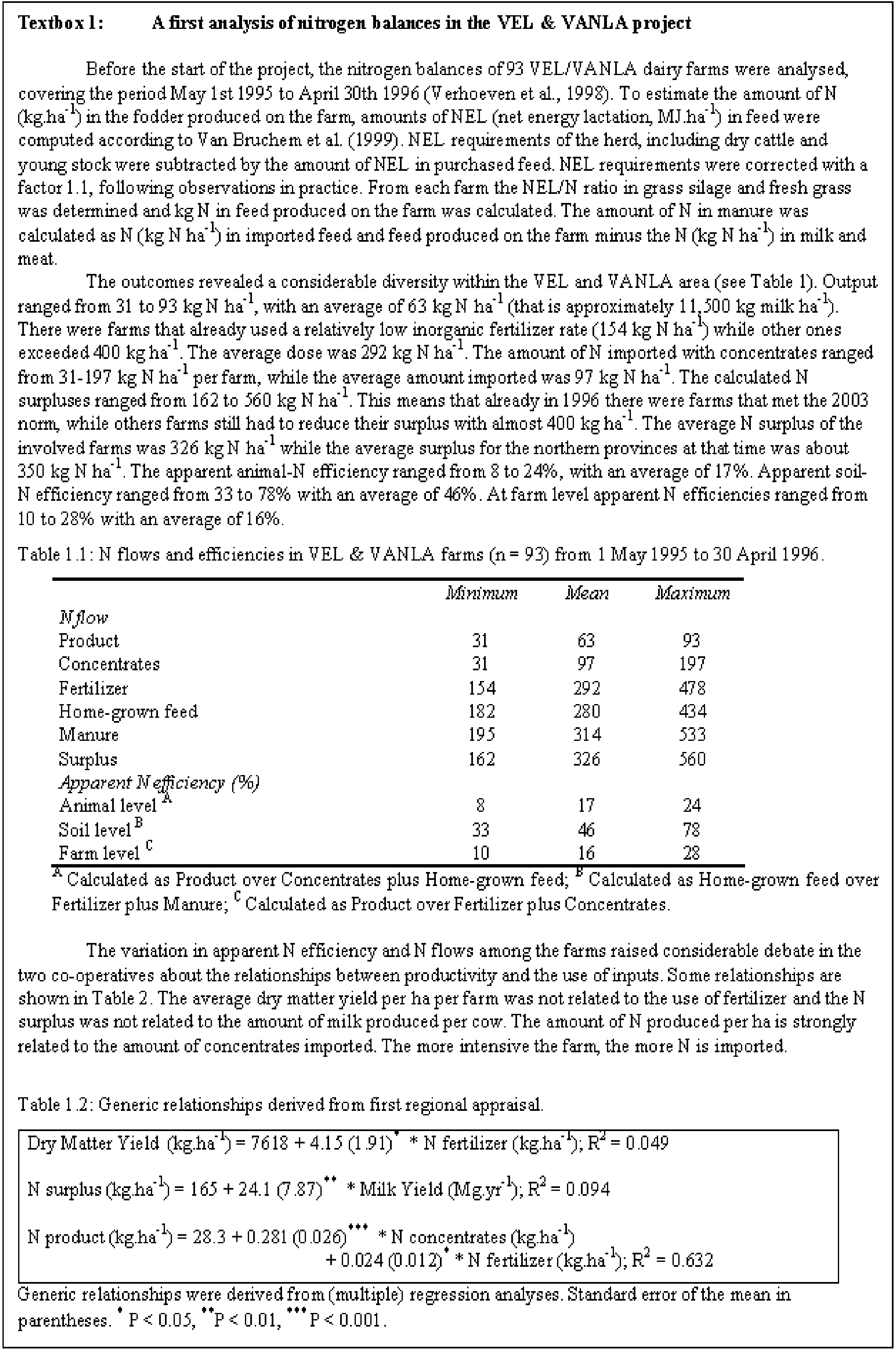
An initial analysis of the N flows of 93 farms in the area showed a large variation in N surpluses between farms (see Textbox 2.1). A number of farms appeared to combine very low N surpluses with high production levels. These farms showed a surprisingly high N efficiency: they became (if they were not already) interesting examples for other farmers in the area. This analysis, widely discussed by local farmers, was subsequently enriched with local insights concerning the most promising practices encountered within the area. According to farmers, differences in efficiency between farms were related to the presence (or absence) of what they referred to as a "particular balance within the farm" (see Hoeksma's story in Van der Ploeg, 2003).

Although the term was not yet used, the promising practices of these farms were understood as 'novelties' (Van der Ploeg *et al*., 2004) that is, as practices that potentially contained solutions that could be applied to other situations. In this way a 'programmatic approach' emerged in which all the subsystems of the farm were considered potentially relevant in the search for sustainability. Subsequently, re-balancing became an increasingly central and self-evident notion: the manure, the soils, the grassland management, the feeding strategies, the quality and composition of the milk could all be changed individually and be recombined in new ways that would result in more acceptable outcomes.

At that time, the scientists (C in figure 2.1) who had performed the analysis (described in Textbox 2.1) had developed the hypothesis that optimising the 'animal' subsystem might prove counterproductive in reducing N surpluses, as this might induce negative effects at the whole farm level (Van Bruchem *et al*., 1999a). Rather, a combination of different elements of scientific knowledge with farmers' insights, led to the formulation and subsequently instigation of a programme with a more specific focus on sustainable and locally appropriate solutions. In contrast to the, then emerging, national agro-environmental policy, (which was technologically oriented) this programme focused on changes in management style. It was adapted to local conditions (e.g. the small-scale landscape) and oriented towards an overall re-balancing and downgrading, rather than a partial downgrading (Van der Ploeg *et al*., 2004).

The benefits of this approach were quite obvious. Scientists wanted to test their theoretical framework in practice and farmers felt the need to make their practices more explicit, more understandable and more defendable. The programme was, admittedly, a hybrid - especially in the beginning. Although reference could be made to specific scientific insights (as will be shown throughout this chapter), these were segmented, isolated, not tested on a broader scale and, as yet, not combined. The VEL and VANLA nutrient management project can be considered as a first attempt to a) systematically combine local and (new) scientific insights and b) put them into practice, monitor and, if needed, adapt them. An agreement with the Minister of Agriculture permitted the creation of a niche or “field laboratory” (Stuiver *et al.,* 2004) (D in figure 2.1) in which the programme could be set up.

Textbox 2.1: A first analysis of the N balances in the VEL and VANLA project



Textbox 1: A first analysis of nitrogen balances in the VEL & VANLA project

Before the start of the project, the nitrogen balances of 93 VEL/VANLA dairy farms were analysed, covering the period May 1st 1995 to April 30th 1996 (Verhoeven et al., 1998). To estimate the amount of N ($kg.ha^{-1}$) in the fodder produced on the farm, amounts of NEL (net energy lactation, $MJ.ha^{-1}$) in feed were computed according to Van Bruchem et al. (1999). NEL requirements of the herd, including dry cattle and young stock were subtracted by the amount of NEL in purchased feed. NEL requirements were corrected with a factor 1.1, following observations in practice. From each farm the NEL/N ratio in grass silage and fresh grass was determined and kg N in feed produced on the farm was calculated. The amount of N in manure was calculated as N (kg N ha^{-1}) in imported feed and feed produced on the farm minus the N (kg N ha^{-1}) in milk and meat.

The outcomes revealed a considerable diversity within the VEL and VANLA area (see Table 1). Output ranged from 31 to 93 kg N ha^{-1}, with an average of 63 kg N ha^{-1} (that is approximately 11,500 kg milk ha^{-1}). There were farms that already used a relatively low inorganic fertilizer rate (154 kg N ha^{-1}) while other ones exceeded 400 kg ha^{-1}. The average dose was 292 kg N ha^{-1}. The amount of N imported with concentrates ranged from 31-197 kg N ha^{-1} per farm, while the average amount imported was 97 kg N ha^{-1}. The calculated N surpluses ranged from 162 to 560 kg N ha^{-1}. This means that already in 1996 there were farms that met the 2003 norm, while others farms still had to reduce their surplus with almost 400 kg ha^{-1}. The average N surplus of the involved farms was 326 kg N ha^{-1} while the average surplus for the northern provinces at that time was about 350 kg N ha^{-1}. The apparent animal-N efficiency ranged from 8 to 24%, with an average of 17%. Apparent soil-N efficiency ranged from 33 to 78% with an average of 46%. At farm level apparent N efficiencies ranged from 10 to 28% with an average of 16%.

Table 1.1: N flows and efficiencies in VEL & VANLA farms (n = 93) from 1 May 1995 to 30 April 1996.

	Minimum	*Mean*	*Maximum*
N flow			
Product	31	63	93
Concentrates	31	97	197
Fertilizer	154	292	478
Home-grown feed	182	280	434
Manure	195	314	533
Surplus	162	326	560
Apparent N efficiency (%)			
Animal level ^{A}	8	17	24
Soil level ^{B}	33	46	78
Farm level ^{C}	10	16	28

^{A} Calculated as Product over Concentrates plus Home-grown feed; ^{B} Calculated as Home-grown feed over Fertilizer plus Manure; ^{C} Calculated as Product over Fertilizer plus Concentrates.

The variation in apparent N efficiency and N flows among the farms raised considerable debate in the two co-operatives about the relationships between productivity and the use of inputs. Some relationships are shown in Table 2. The average dry matter yield per ha per farm was not related to the use of fertilizer and the N surplus was not related to the amount of milk produced per cow. The amount of N produced per ha is strongly related to the amount of concentrates imported. The more intensive the farm, the more N is imported.

Table 1.2: Generic relationships derived from first regional appraisal.

Dry Matter Yield $(kg.ha^{-1}) = 7618 + 4.15\,(1.91)^{*} * N\ fertilizer\ (kg.ha^{-1}); R^2 = 0.049$

N surplus $(kg.ha^{-1}) = 165 + 24.1\,(7.87)^{**} * Milk\ Yield\ (Mg.yr^{-1}); R^2 = 0.094$

N product $(kg.ha^{-1}) = 28.3 + 0.281\,(0.026)^{***} * N\ concentrates\ (kg.ha^{-1})$
$+ 0.024\,(0.012)^{*} * N\ fertilizer\ (kg.ha^{-1}); R^2 = 0.632$

Generic relationships were derived from (multiple) regression analyses. Standard error of the mean in parentheses. * $P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

In this chapter we will discuss both the theoretical background and practical outcomes of this research project. Section 2.2 deals with some crucial theoretical elements that informed this research project. Section 2.3 describes the way these elements were moulded into the nutrient management project. Section 2.4 provides a summary of the technical results of the project and Section 2.5 concludes by examining the broader impact of the project.

2.2 Crucial theoretical elements

2.2.1 Technology in society

The farmers in the VEL and VANLA area developed a proactive attitude towards the reduction of nutrient surpluses. In 1992, they were among the first farmers in the Netherlands to document the inputs and outputs of nutrients on their farms (Anon., 1994). However, these farmers found that several of the technologies being proposed (or imposed) as ways to improve N efficiency seemed inappropriate or counterproductive. Legislation requiring the injection of slurry into the soil was a prime example of this. The rationale behind this legislation was that injection reduces emissions of ammonia and increases the efficiency of use of N significantly in comparison with surface application (Van der Meer *et al*., 1987). However, farmers in the VEL and VANLA region were concerned that injection of slurry into the soil would damage the topsoil and soil life and the heavy machinery would cause soil compaction, adversely affecting the sward quality and productive capacity of their permanent grasslands. Furthermore, the size of the machinery was inappropriate for the small fields in the area and, as injection was mostly done by contract-workers this would increase the costs of manure application, conflicting with the economical farming style of most farmers in the area, (Van der Ploeg, 2000). As a result, farmers considered injection of slurry as a threat to their production system rather than a tool to improve N efficiency.

This example illustrates that the success or acceptability of a single technology not only depends on its technical capacity but also on its effects on the entire production system, its environment and specific local conditions. A technology can never be isolated from its surrounding environment. Innovation, adoption and adaptation are all embedded in socio-technical regimes and overall socio-technical landscape. In this respect a promising technology or novelty needs to be evaluated from a technology-in-society perspective (Rip & Kemp, 1998). This perspective focuses on the interaction between technology and society and stresses the processes of co-evolution between technological innovations and social context.

2.2.2 System approach

The efficiency of nutrient use in Dutch agriculture significantly decreased from 1950 onwards, due to easy and cheap access to external inputs and management strategies based on the rationale of maximising short-term profits (Van Bruchem *et al.*, 1999a). Relating these more generalised concerns to the level of the individual farm unit, requires the adoption of integrative methodologies (Waltner-Toews, 1997). For example, flows of nutrients within a dairy farm can be usefully understood by describing the farm as a single system, subdivided into four subsystems: soil, feed, animals and manure. This type of system approach is often used when seeking to reduce N surpluses at the farm level (e.g. Jarvis *et al.*, 1995; Aarts, 2000) and provided the basis for the MINAS approach. A system approach makes it explicit that all subsystems are interrelated and changes in one part of the system affect the other components of the system. When production systems become unbalanced the efficiencies can decrease, due to negative interactions between the subsystems. On the other hand, in more balanced situations, mutually beneficial effects can arise and the performance of the production system as a whole may surpass the total of the subsystems (Schiere & Grasman, 1997). To optimise the outcomes of the whole system it is important to seek to improve the coherence, or positive interactions, among the subsystems, rather than aim to maximise the performance of the subsystems in isolation.

The level of milk production per cow provides an instructive example of this principle. In terms of the individual cow a high level of milk production is more efficient, as proportionately fewer nutrients are required for its maintenance. However, if the roughage produced on the farm does not provide enough nutrients to reach this high production level, external feed (e.g. concentrates) will be required. This implies a decrease of the production efficiency at the whole farm level, due to an imbalance (negative interaction) between the availability of roughage and the milk production level per cow.

2.2.3 Downgrading and re-balancing

The system approach provides one way to describe and understand a phenomenon that the VEL and VANLA farmers recognised as crucial, namely the creation of 'a particular balance within the farm'. Farming can also be described as ‘the art of fine tuning’. Resources such as fields, cattle, crops, manure need to be unravelled and re-moulded in order to create combinations that are as productive and sustainable as possible and this unravelling and remoulding requires fine-tuning[3] (Groen *et al.*, 1993; Portela, 1994; Bouma, 1997; Van der Ploeg, 2003). With increasing insights (i.e. with

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[3] The art of fine-tuning also involves the wide range of growth factors involved in agricultural production processes. Because of the mutual improvement of resources, as well as the mutual adjustment of relevant growth factors, specific, endogenous development trajectories and potentials are emerging and being sustained.

developing local and/or scientific knowledge), and through adjusting individual growth factors (of whatever type), the whole is constantly being re-balanced. Hence, step-by-step improvements are created. Both these theories imply that a new optimal equilibrium in the dairy farming system requires a fundamental shift in management style from one of up-scaling and the management of single-factors, to downgrading and the implementation of multi-factor strategies.

Downgrading implies a reduction in the use of some growth factors in order to create a new balance that allows farming to be both ecologically and economically sustainable (Van der Ploeg *et al*., 2004). When this downgrading is well articulated, it can result in an improved income as a result of immediate savings (on fertiliser for example), but possibly also as a result of a range of indirect effects (for instance the improved health of the cows, reduced costs for animal replacement, etc). Generally, the process of re-balancing is slow, incremental and often barely perceptible, although careful empirical analysis can highlight its presence and potential (Swagemakers, 2002). In periods of transition (such as the present time) re-balancing of farming systems as a whole comes to the fore. The reduction of N surpluses entails a reduction of external resources (mostly concentrates and fertiliser). This implies that farmers become more dependent on their own specific resources (such as soil, roughage and manure) and need to adapt their production system to their specific conditions. For instance, a reduction in the use of fertiliser will lead to a change in the quality of the pastures and the roughage produced. These changes in turn require an adaptation - or a re-balancing - of the type and amount of concentrates used, the optimal productivity and longevity of the cows, ideal breed of the cows, the type of grassland, and so on and so forth. Eventually, this downgrading will lead to an increase of heterogeneity amongst farms and farming practices. This in turn implies that the need for farm and locally specific solutions will increase and that generic solutions will become less relevant.

2.2.4 Farmers' knowledge

A fourth important element of the nutrient management project was the direct contact between farmers and scientists and the use that was made of farmers' knowledge in the project. Farmers have years of experience and knowledge in organising and optimising their farms. This knowledge is not only based on scientific insights but farmer experimentation and experiences also play an important role (Stuiver *et al*., 2004). Often these two types of knowledge are expressed in different ways. To understand the underlying principles of improving nutrient efficiency, farmers and scientists had to explain their knowledge and experiences to each other. Farmers were encouraged to experiment with nutrient management on their farms and the results were discussed thoroughly with other farmers and scientists. These discussions were crucial:

they contributed to the construction of shared hypotheses. Farmers and scientists enhanced their understanding about the data in the model and came to understand why nutrient flows varied between farms and how farmers influenced this by managing nutrient flows.

Besides increasing knowledge, these discussions generated enthusiasm amongst farmers and scientists and stimulated the farmers to actively implement new management strategies. The discussions also strengthened the confidence of the farmers in their own knowledge and decision making capabilities. Another consequence of the direct contact between farmers and scientists was to reduce the risk of misunderstanding between the two groups: differences in perceptions and language had to be overcome in direct discussion. During an evaluation of the project one of the farmers stressed the importance of these elements of the project:

'Social cohesion, curiosity, farmers teaching farmers, these all are very interesting elements of the project. There is a lot of knowledge at 'Wageningen'[4]*, but the farmers do not know what to do with it. But through encouraging farmers to learn together, the results become clearer for the farmers'.*

This illustrates the importance of the direct interaction between the farmers and scientists involved in the project. The farmer describes the project as a joint learning process in which scientific and experiential knowledge were both crucial elements. In this respect the project can be seen as a field laboratory (Stuiver *et al.*, 2003). This farmer also stresses the practical benefits brought about by the increase of the availability and applicability of scientific knowledge created by the project.

2.3 Hypotheses of the project

2.3.1 Soil-plant-animal-manure approach

The farmers and scientists shared a common interest in finding out whether N surpluses could be reduced without causing a loss in production. Possibilities for increasing the N efficiency of mixed farming systems were already being investigated at the A.P. Minderhoudhoeve prototype experimental farm in Swifterbant (from now on called the APM) (Lantinga & Van Laar, 1997). To a certain extent this farm acted as an inspiration and starting point for the participants in the VEL and VANLA-project. This section discusses how the VEL and VANLA nutrient management project incorporated the different influences described in the previous sections.

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[4] Wageningen University and Research Centre

The analysis described in Textbox 2.1 was presented to the farmers in the form of a "soil-plant-animal-manure-picture" (see figure 2.2). Later on, this uncomplicated and holistic picture became the 'trademark' of the project. Although it did not include all the available scientific knowledge about N flows at farm level, the picture summarised the N flows on a dairy farm in an accessible way and also introduced the notions of a system approach, the importance of efficiency and the interdependency of the different subsystems. Analysis of the successful strategies of local innovators was incorporated into this model in order to try to develop a novel strategy capable of further reducing N surpluses.

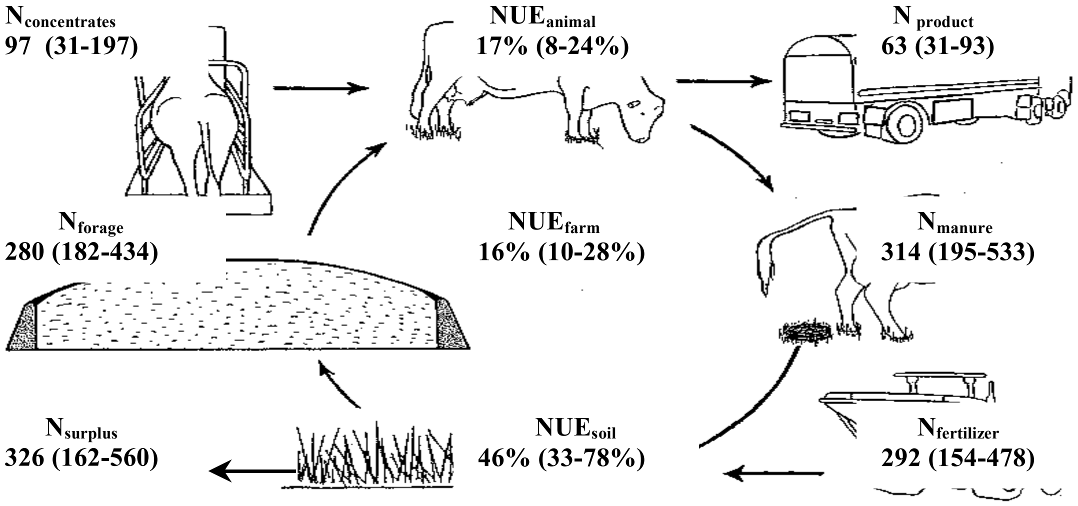

Figure 2.2 *The characteristic soil-plant-animal-manure picture, showing average, minimum and maximum N flows (kg N ha^{-1} year^{-1}) and apparent nitrogen use efficiencies (NUE in %) of 93 farms in the VEL & VANLA area in 1995/1996 (for further explanation see textbox 2.1).*

At around the same time, Lantinga & Groot (1996) concluded that under integrated grazing and cutting management N losses per unit product are minimised at a rate of 200 kg mineral N ha^{-1} yr^{-1}, leading to a reduction in production of only 10% compared to grassland fertilised with 400 kg mineral N ha^{-1} yr^{-1}. Based on these and similar findings in Ireland and England, Lantinga stated in a popular magazine (Muller, 1999) that the input of chemical fertiliser at farm level could be much lower than the Dutch fertiliser recommendations at that moment without a significant loss in grassland production.

On this basis, a significant reduction in levels of fertiliser use was formulated as one of the main priorities in the project. It was concluded that the key to reducing N surpluses was to improve the N efficiency of the soil. A more efficient soil would need fewer inputs (manure and/or fertiliser) to produce the same output (roughage). To achieve this it would be necessary to improve the utilisation of N contained within the manure produced on the farms. This could then lead to a gradual decrease in the need for *external* fertiliser. As in other projects running at the same time (e.g. Aarts, 2000), this became the main aim.

Cows have a low digestive efficiency for N (e.g. Castillo *et al.*, 2000). Approximately 75–80% of the N ingested by a dairy herd is secreted in faeces and urine. Most farms in the Netherlands do not separate faeces and urine, but produce slurry manure, which has high inorganic N content, which is highly volatile and easily lost to the atmosphere. Reducing volatilisation increases the efficiency of use of the N contained in the slurry. There are different ways to approach this. One strategy involves employing technical solutions, such as low emission stables or soil injection of manure. Another involves preventing emission by decreasing the inorganic N content of the slurry. The VEL and VANLA project choose to explore the possibilities of this second strategy. They recognised such a strategy might reduce the need for expensive technical solutions such as roofing manure storage areas, installing low emission stables or injecting the slurry manure into the soil.

However, as noted earlier, a change in one part of the farming system also requires a re-balancing of the whole. A reduction in the inorganic N content of slurry manure (combined with a lower fertiliser use) implies that plant growth will become more dependent on organic N. This however is not directly available to the plant but has to be converted by soil micro-organisms. This led the VEL and VANLA project to seek to change soil management so as to improve conditions for soil micro-organisms, through avoiding the use of heavy machinery and experimenting with microbial additives. They adopted the C:N (carbon : N) ratio of the slurry manure as an indicator of its quality. Increasing the C:N ratio of the slurry implied a change in the cows' diets, reducing the amount of protein and increasing the fibrous content. In addition, straw was added to the slurry and some farmers used additives that they expected to further improve the C:N ratio.

It was also anticipated that a gradual decrease in the amount of fertiliser used combined with a postponement of the cutting moment would lead to a simultaneous decrease in the N content and increase in the fibre content of the home-grown roughage. This roughage would therefore play a key role in the transition to high fibre/low protein diets. These diets would, in turn, increase the C:N ratio, and decrease the inorganic N content of the manure. Together these changes made a coherent and complete hypothesis. The challenge for the farmers was to apply these measures gradually, in such a way as to maintain their production levels. If they succeeded, the N efficiency of their farms could gradually be increased and N flows through the system could be reduced.

2.3.2 A typical feeding strategy

A key element of the VEL and VANLA project was to develop a new feeding strategy. When formulating dairy cow diets, different objectives can be used. For example, one can aim to maximise milk production (quantity and/or composition), the health of the cows, or to reduce the amount (and cost) of purchased feed. Bearing these objectives in mind, farmers search for an optimal equilibrium that takes account of the specific conditions on their farms and their preferred farming style (Van der Ploeg, 2003).

Several researchers have discussed the importance of feeding strategy in the context of reducing N surpluses (Tamminga, 1996; Castillo *et al.*, 2001; Børsting *et al.*, 2003). If a reduction of N surpluses is a priority, then diet formulation becomes more dependent on the resources within the farming system. This will have the combined effect of reducing the amount of N imported in purchased feed and improving N efficiency at animal level. Diets with protein values that just meet requirements can still maintain high production levels, while reducing levels of N intake. Under these conditions the N use efficiency of individual animals can be increased from around 20% to around 35–40% (Tamminga, 1996). Theoretically, the N loss of a 600 kg cow, producing 25 kg milk d^{-1} (5.2 g N kg^{-1}) and fed on a well-balanced (in terms of energy and protein) diet could be as little as 170 g N d^{-1}. In this ideal situation the efficiency of use of dietary N is almost 45% (Van Vuuren & Meijs, 1987). A very small proportion of N is lost to the skin and hair. The remainder is endogenous urinary N and metabolic faecal N excess related to maintenance and milk production processes (about 70 and 100 g N d^{-1}, respectively). Assuming a daily dry matter (DM) intake of about 20 kg cow^{-1} d^{-1}, the N content of the diet can be calculated to be about 15 g kg^{-1} DM. This is equivalent to a crude protein (CP) content of 95 g kg^{-1} DM. However, in practice this ideal situation can never be reached because in such a protein-poor diet the protein-nutritional value (DVE)[5] content will be insufficient to produce enough milk protein. Feeding experiments at APM have revealed that, in practice, the efficiency of utilisation of dietary N can reach about 35% at most with cows producing 8500 kg milk yr^{-1} (5.4 g N kg^{-1}). In this situation, the optimal N content of the diet was about 20 g kg^{-1} DM or 125 g CP kg^{-1} DM.

The strategy developed at APM and promoted in the VEL and VANLA project sought to go beyond merely reducing protein content (see Figure 2.3). Reduction of the surpluses at farm level is not only a matter of efficient use of N at animal level. As noted in previous sections, animal efficiency is not the most important step in the reduction of surpluses at farm level. Improving N efficiency at farm level involves increasing the use of internal farm resources, specifically the contained N in manure.

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[5] DVE stands for Darm Verteerbaar Eiwit or true protein digested in the small intestine, for a full description see (Tamminga *et al.*, 1994)

The production of high quality manure should be no less important than the production of high quality milk. In terms of the system approach: the optimisation of the animal subsystem should be subordinate to the optimisation of the whole system. The main difference between ‘regular’ low protein diets and the diets fed at APM and promoted at the VEL and VANLA farms was that the latter also aimed to increase the diets’ fibre content. The underlying idea was to increase the organic matter content of the manure (and thereby increase its C:N ratio) by increasing the amount of indigestible matter in the diet (Tamminga *et al*., 1999).

High fibre diets can be expected to yield several positive effects. First of all, an increased amount of indigestible matter in the rumen decreases the risk of rumen acidosis by increasing the size of the fibre pool in the rumen and mechanical stimulation of the rumen wall (Van Soest, 1994). In the second place, sufficient indigestible matter stimulates rumination, which encourages more efficient use of N in the rumen due to the reflux of N via saliva and the rumen wall (Van Soest, 1994). Furthermore, the passage of more undigested organic material through the gut changes the fermentation pattern in the large intestine and leads to an increase of endogenous N. This N can be used for the production of microbial biomass in the large intestine (Van Soest, 1994; Tamminga *et al*., 1999) and leads to a shift in N excretion from urine to faeces.

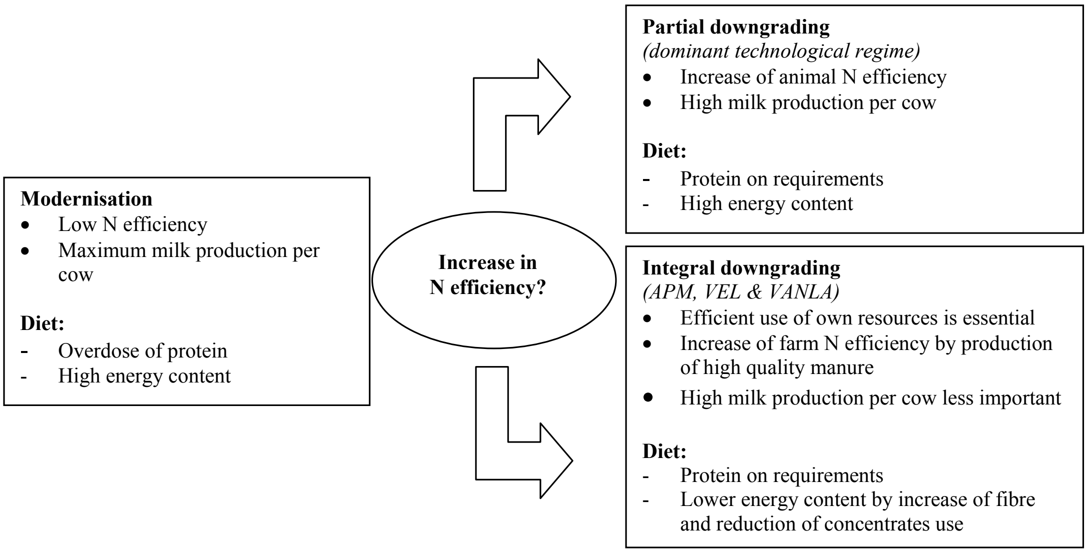

Figure 2.3 *Schematic overview of the effects on diet type from two pathways of downgrading external N in dairy farming systems*

Of course negative aspects of the high fibre/low protein diets can also be expected. First of all, less readily digestible diets do not provide the same amount of nutrients per kg dry matter as diets with high digestibility (Tamminga, 1995). Thus the same amount of feed intake contains fewer available nutrients, which has possible implications for milk production levels. Van Bruchem *et al.* (2000) compared two imaginary extreme diets and demonstrated that, in order to reach the same production level, the dry matter intake of a low energy/low protein diet would have to be 135% of the intake of the high energy/high protein diet. Furthermore, one of the main limiting factors of feed intake, is the cell wall content of the feed, which is intrinsically high in high fibre diets. This implies that a high feed intake will be more difficult to achieve with these low energy/low protein diets. Therefore, to provide enough nutrients for a high milk production level, the intake capacity of low energy/low protein diets is of crucial importance. Tamminga & Van Vuuren (1996) proposed the following formula for predicting feed intake:

$$DMI\ (g\ d^{-1}) = 6382 + 33.4\ FPCM + 11.3\ LW + 5.06\ CONC - 6.24\ NDFR \qquad (2.1)$$

DMI = Dry Matter Intake
FPCM = Fat and Protein Corrected Milk ($g\ kg^{-0.75}$)
LW = Live weight of the cow (kg)
CONC = Proportion of concentrate dry matter ($g\ kg^{-1}$)
NDFR = Neutral Detergent Fibre content of the roughage ($g\ kg^{-1}\ DM$)

This model has quite reliably predicted DMI for diets over a wide range of circumstances. However, experiments with total mixed rations conducted at the APM, which compared feed intake predictions based on this formula with the measured results, showed that this formula significantly underestimated the intake capacity of these diets. While the model predicted a DMI of 17.5 and 21.4 kg DM day^{-1} for the late and early lactation stages respectively the real DMI was far higher, at 20.2 and 24.8 kg DM day^{-1} respectively with milk productions of 24.2 and 36.3 kg day^{-1} FPCM. This suggests that the production possibilities based on low energy/low protein diets may be higher than expected, due to an unexpectedly higher feed intake capacity. Therefore, stimulation of the DMI became another important issue within the VEL and VANLA project. Most important in this respect is improving the appeal of grass silages.

Whilst important, the volume of available nutrients is not the only limiting factor for milk production. The type of available nutrients also plays an important role. For milk production, nutrients can be subdivided into precursors for three groups of components; lactose (glucogenic nutrients), protein (aminogenic nutrients) and fat (ketogenic nutrients). Model-based predictions (Dijkstra *et al.*, 1992) show that glucogenic nutrients are main limiting for milk production in the Netherlands. In relatively high protein diets the shortage of glucogenic nutrients can be replenished by glucogenic amino acids, while de-amination increases urinary urea excretion. With low protein diets, fewer amino acids are available for glucogenic purposes and a shortfall of glucogenic nutrients could lead to a drop in milk production or milk protein content. Furthermore, high fibre diets stimulate the production of ketogenic nutrients (fat-precursors) leading to an increase of the fat content of the milk. Given the higher prices paid for protein (in comparison with fat) a high fat to protein ratio is not very attractive to Dutch dairy farmers. It is therefore extremely important to assemble a well-balanced diet that can provide enough (non-aminogenic) glucogenic precursors. Important factors in this respect are 1) sufficient rumen available energy to provide optimal microbial protein production and 2) sufficient availability of non-degradable starch as direct glucogenic precursors. In the longer term, breeding strategies based on the criterion of high milk protein content could also be developed.

2.4 A summary of technical results

2.4.1 Data collection and farm characteristics

The VEL and VANLA project started in 1997 and involved 60 farmers. In the first years the project team consisted of only a few members. The most important job for the project team was to stimulate the farmers and guide them by a rapid exchange of results and insights (Stuiver & Wiskerke, 2004). The main aim was not to collect data for scientific research but to improve results at the farm level. Therefore, it was not possible for the team to collect detailed and accurate data for every farm. Choices had to be made in data collection. The results of this monitoring/data collection and the conclusions that can be drawn from them are discussed later, in Section 2.5.

Despite this, continuous monitoring of data and knowledge exchange were important pillars of the project. The farmers were continually adjusting the component parts of their farms: their fields, their manure, their management, their feeding etc. in order to find a new ecological and economical optimum, one characterised by an undiminished level of production, considerably reduced N surpluses and, in the end, a higher income. The farmers worked together with the scientists and explored the possibilities for their specific situation, using the whole toolbox of available measures. This diversity of experience makes the project rich and complex but, from a conventional scientific (and reductionist) perspective, also controversial, as it is difficult to separate or quantify the effects of individual measures separately from the others.

Table 2.1 provides details of a number of key characteristics of the farms participating in the project[6]. The table shows that, in general the farms increased their total size during the project. This increase mostly involved increasing the available

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[6] The number of farms in the tables varies. This is a result of the inaccuracy of some data. Farms with inaccurate data in one year are not presented.

grassland area, while the percentage of the area used for silage maize remained stable. There was also an increase in total milk production from 523 tonnes milk year^{-1} in 1997/98 to 600 tonnes milk year^{-1} in 2002/03. Production intensity and milk production per cow both remained relatively stable throughout the project. There was a slight decrease in stocking density, mainly due to a reduction of the number of young stock maintained on the farms. The fat and protein content of the milk produced remained stable.

Table 2.1 *Development of average farm characteristics during the nutrient management project*

	1997–1998	*1998–1999*	*1999–2000*	*2000–2001*	*2001–2002*	*2002–2003*
Number of farms	50	50	50	50	49	48
Area grass (ha)	42.7	43.9	45.1	46.1	46.6	49.5
Area silage maize (ha)	2.2	2.5	2.4	2.3	2.7	2.6
Total milk production (Mg year^{-1})	523	534	560	573	593	600
Number of milking cows	67.7	69.4	70.5	73.3	77.3	78.7
Rate of young stock (10 milking cows^{-1})	8.2	8.2	7.7	7.6	7.2	7.4
Stocking Density (GVE [a] ha^{-1})	2.0	1.9	1.9	1.9	2.0	1.8
Production intensity (kg milk ha^{-1})	11,662	11,534	11,533	11,651	11,844	11,449
Milk production (kg cow^{-1})	7,651	7,597	7,833	7,754	7,609	7,685
Fat content milk (%)	4.41	4.38	4.34	4.39	4.42	4.42
Protein content milk (%)	3.44	3.45	3.45	3.43	3.45	3.46

a) GVE = Groot Vee Eenheid, stands for the total number of cattle converted to adult cattle units.

2.4.2 Farm level N surpluses

The main goal of the project was the reduction of N surpluses. Table 2.2 shows the changes in N balances of the participating farms. The average N surplus decreased from 299 kg ha^{-1} in 1997/1998 to 156 kg ha^{-1} in 2002/2003. By 2002/2003, 77% of the VEL and VANLA farms met the thresholds set by legislation for 2003 (the following growing season). The efficiency of N use at the farm level has increased from an average 19% in 1997/1998 to 31% in 2002/2003. The decrease of the N surplus was mainly achieved through a reduction of fertiliser inputs, which fell from 270 kg N per ha in 1997/1998 to 126 kg N per ha in 2002/2003. However, the average N output (in milk and meat) did not change over this period, indicating that the farms were able to maintain their productivity. Over this six year period there was no increase in the input of feed-based N onto the farms, indicating that it was not necessary to compensate for the reduction of fertiliser N through extra feed N inputs.

Table 2.2 *Progress in MINAS N balance (mean ± standard deviation) of the VEL & VANLA farms over the period 1997/98–2002/03 (n=50)*

	1997–1998	*1998–1999*	*1999–2000*	*2000–2001*	*2001–2002*	*2002–2003*
N input (kg N ha^{-1})	369±77	336±84	284±76	244±72	240±70	227±57
• Feed	97±30	101±30	93±28	89±25	102±31	99±31
• Inorganic fertilizer	270±69	233±73	181±72	149±63	134±58	126±39
• Organic manure	2±9	2±8	10±21	6±13	4±10	2±10
N output (kg N ha^{-1})	70±19	72±14	70±16	69±13	71±12	71±14
• Milk	57±12	59±10	59±11	59±10	60±12	59±11
• Meat	10±4	11±4	10±3	10±4	11±4	12±6
• Roughage	1±6	1±3	0±5	0±0	0±1	0±2
• Organic manure	2±8	1±8	1±5	0±1	0±1	0±1
Surplus (kg N ha^{-1})	299±82	264±84	214±69	175±65	169±62	156±48
N efficiency at farm level (%)	19±5%	21±6%	25±6%	28±6%	30±6%	31±6%
Farms that meet legislation 2003 (%)	8%	14%	31%	44%	63%	77%

In Figure 2.4 the N surplus of the VEL and VANLA farms is compared with the results of the Farmers' Data project (Doornewaard *et al.*, 2002) and a reference group of dairy farms in Friesland (Anon., 2003). This graph shows that all three groups had considerable success in reduction of N surpluses although the surpluses remain higher on the farms of the reference group. It is worth noting that considerably more farmers from the Vel and Vanla project meet the 2003 target thresholds farms, compared to those from the Farmers' Data project (77% and 56% respectively). Moreover many farms in the Vel and Vanla project are going further and reducing their surplus below the legal thresholds. The reduction of N surplus in the VEL and VANLA project was also accompanied by a re-moulding of resources and the re-balancing of the soil-plant-animal-manure system. The main features of these changes are summarised below.

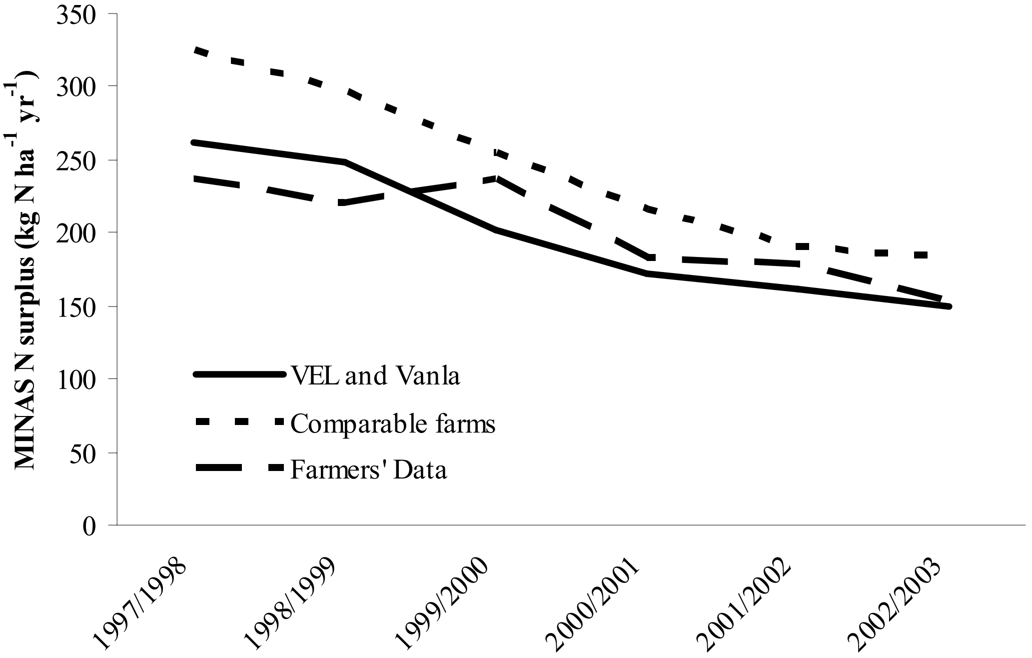

Figure 2.4 *Progress of MINAS N surplus of the VEL and VANLA farms in comparison with the Farmers' Data project (Doornewaard et al., 2002) and a reference group of local farms (Anon., 2003)*

2.4.3 Grass silage composition

Grass silage plays an important role in the soil-plant-animal-manure-system. On most dairy farms, grass or grass silage forms the major part of the cows' diet. In terms of system theory it constitutes the most important link between the soil and animal subsystems. One of the main aims of the project was to produce silage with a lower CP (crude protein) content (mainly as a result of the reduction of fertiliser use) and a higher CF (crude fibre) content (by cutting the grass at a more mature stage). In this way the silage would provide diets that were higher in fibre and lower in protein.

The chemical composition of grass silage depends on several other factors than the fertilisation level and maturity of the grass at cutting. Weather conditions play a particularly important role in determining these. To obtain an idea about their influence, the composition of silage produced on the VEL and VANLA farms between 1997 and 2001 was compared with the national average (Anon., 2002). The results (Table 2.3) show considerable annual fluctuations for both groups of farms and we assume that a large part of this variation is due to differences in weather conditions that applied equally to both groups.

Table 2.3 *Grass silage characteristics (mean ± standard deviation) of the VEL and VANLA (V&V) farms, in the 1997–2001 period, compared with national (BLGG) characteristics (Anon., 2002)*

Year	*Source*	*n*	*DM* *(g kg^{-1})*	*CP* *(g kg dm^{-1})*	*CF* *(g kg dm^{-1})*	*Sugar* *(g kg dm^{-1})*	*DVE* [a] *(g kgdm^{-1})*	*OEB* [a] *(g kgdm^{-1})*
1997	V&V	111	453 ± 84	179 ± 21	248 ± 13	64 ± 34	65 ± 8	66 ± 27
	BLGG		436	182	253	64	66	68
1998	V&V	146	432 ± 95	166 ± 22	250 ± 21	72 ± 35	68 ± 12	48 ± 22
	BLGG		415	174	252	60	70	58
1999	V&V	144	503 ± 76	158 ± 19	243 ± 15	123 ± 38	74 ± 7	28 ± 19
	BLGG		494	180	242	102	78	50
2000	V&V	112	460 ± 82	167 ± 19	258 ± 15	75 ± 39	72 ± 7	44 ± 24
	BLGG		480	176	256	74	76	51
2001	V&V	97	489 ± 63	155 ± 16	248 ± 30	106 ± 34	74 ± 6	24 ± 16
	BLGG		516	173	251	113	81	37

a) According to Dutch protein evaluation system (Tamminga et al., 1994)

Over the longer term noticeable differences emerge between the two groups. In 1997 (the year before the project started) there was little difference in the CP and CF content of silage produced on farms participating in the project and the national average. During the course of the project, the VEL and VANLA farmers reduced the CP content of their silage. An important consequence of this reduction was the reduction of OEB[7], an indicator of possible surplus rumen N caused by feed stuffs. The reduction of CP content did not lead to a loss of the protein-nutritional value of the silages. The average DVE-content of the silages in the project even showed a slight increase, though this increase was smaller than at national level.

Regular contact with the farmers showed that, in general, they postponed cutting their grass. However, this did not, as anticipated, lead to an increase in the average CF content of silage produced by the VEL and VANLA farmers (at least in comparison with the national average). The figures do however, reveal a growth in the standard deviation of the CF content for Vel and Vanla farms in 2001, indicating that variation in the CF content is increasing. This suggests that, after 4 years of the project, a turning point has been reached in silage making, with different farmers adopting different strategies and achieving different results. In turn, this illustrates a growth in the heterogeneity of farms and their strategies.

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[7] OEB stands for Onbestendig Eiwit Balans or degraded protein balance, for a full description see (Tamminga *et al.*, 1994)

2.4.4 Diet composition

From the second year of the project onwards (autumn 1999) the project also focused on changes in diet composition. From the first findings at the APM experimental farm, guidelines were formulated for diet composition on the VEL and VANLA farms. These guidelines can be summarised as follows:

- Limit CP (Crude Protein) to ≤ 150 g.kg^{-1} dm
- Limit OEB (degraded protein balance) to 0 g^{-1} d
- DVE-values (true protein digested in the small intestine) must fulfil requirements for maintenance and milk production
- Limit VEM[8] (net energy content) to ≤ 900 kg^{-1} dm
- Limit the use of concentrates to ≤ 25 kg 100 kg^{-1} FPCM.

Farmers were encouraged to work towards these guidelines. Diet composition and intake were recorded three times during the winter months (although no data were recorded in 2000/2001).

Table 2.4 *Winter diet and production characteristics (mean ± standard deviation) of the VEL & VANLA farms: 1998/99–2001/02*

Year	*1998–1999*	*1999–2000*	*2000–2001*
Number of farms (n)	46	46	46
Average diet composition			
VEM (kg^{-1} dm)	939 ± 32	936 ± 33	940 ± 27
CP (g kg^{-1} dm)	167 ± 15	157 ± 13	157 ± 12
OEB (g cow^{-1} day^{-1})	589 ± 218	312 ± 222	277 ± 188
CF (g kg^{-1} dm)	198 ± 17	201 ± 13	203 ± 18
Concentrates use			
(kg cow^{-1} day^{-1})	7.1 ± 1.7	6.4 ± 1.6	6.4 ± 1.6
(kg 100 kg^{-1} FPCM)	30.6 ± 6.7	27.4 ± 5.6	24.8 ± 5.1
Roughage			
VEM from own farm (%)	60.1 ± 8.1	63.4 ± 6.7	62.2 ± 7.0
OEB (g kg^{-1} dm)	38 ± 19	18 ± 17	12 ± 14
CP (g kg^{-1} dm)	157 ± 21	144 ± 18	140 ± 16
CF (g kg^{-1} dm)	235 ± 16	236 ± 15	241 ± 20
Production			
Milk (kg cow^{-1} day^{-1})	23.9 ± 3.1	23.8 ± 3.2	25.6 ± 3.2
Fat content (%)	4.50 ± 0.21	4.55 ± 0.18	4.60 ± 0.21
Protein content (%)	3.46 ± 0.12	3.49 ± 0.10	3.51 ± 0.13
N-efficiency (%)	24.9 ± 2.5	26.7 ± 2.4	26.6 ± 2.4

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[8] VEM stands for Voeder Eenheid Melk. Dutch standard for Net Energy lactation (1 VEM = 6.9 kJ)

Table 2.4 shows the changes in diet composition over the first years of the project. The guidelines and the first results were thoroughly discussed by small groups of farmers. In 1999/2000 a significant reduction of the average protein content (CP) was achieved and this was stabilised after two years. This reduction of the CP was mainly attributable to a reduction of OEB in the diet from 589 g day^{-1} in 1998/99 to 277 g day^{-1} in 2001/02 (Table 2.4). The farmers also succeeded in decreasing the use of concentrates from 30.6 kg (100 kg)$^{-1}$ FPCM in 1998/99 to 24.8 kg (100 kg)$^{-1}$ FPCM in 2001/02. Under these conditions milk production per cow in winter period increased, as did the fat and protein content of the milk. There was no reduction of the average net energy content (VEM) of the diets in winter and the CF content remained unchanged. Overall these results suggest that the effects of the typical aspect of feeding strategy, i.e. the increase of the amount of indigestible matter in the diet have not (yet) been very pronounced. However, the increase in the fibre in diets has led to other subtle changes whose impact lies outside these dietary characteristics. Apart from changes in silage quality (discussed previously), there has been an increase in the use of small amounts of fibrous products such as nature conservation grade hay and straw which are used to complement diets that have a shortage on fibre.

During the project farmers increased their knowledge about the relationship between the composition of diet and manure, milk production and the health of the cows. As a result they have become more confident in decision-making and less dependent on advice from feed suppliers. Furthermore there has been a tremendous change in perception of the way diets should be composed. Objectives have shifted from high production levels towards manure quality, cow health and economic performance. This is illustrated by the following quotes from farmers in the project:

"In the past we wanted the manure of the cows to be as thin as possible. Then you had the maximum milk production. That is how we did it for years. But the quality of the manure those days was bad. It was an inevitable waste product. Now we try to combine optimal milk production with optimal manure quality. That is quite a different attitude…"

"….Now it is different, we have less sick cows. We feed more fibre, the rumen of the cow has to function properly. We don't ask for that maximum production anymore…. That is our choice."

"I am not looking for that high production anymore. That is not what it is about. With the reduction of feed costs, we are increasing the economic performance"

2.4.5 Milk urea N as a tool

Measurements of Milk Urea N (MUN)[9] provide a simple indicator that can be used to monitor N excretion from lactating dairy cows. It is used as a management tool to improve dairy herd nutrition (Jonker *et al.*, 1998) and can help reduce excessive flows of N within the animal sub-system. Research carried out at the University of Pennsylvania has revealed that average MUN values for cows fed a well-balanced diet typically fall in the range of between 10–14 mg dl^{-1} (Ferguson, 2001). According to the Dutch Research Centre for Cattle Husbandry, optimum MUN for the total herd should be slightly higher, in the range of 11.5–14 mg dl^{-1} (Anon., 1997)[10]. These figures provide a safety margin to ensure that individual cows are not subject to a negative OEB. However, theoretically, OEB values might be zero if the DVE value of the diet is sufficient to meet the cow's dietary requirements. In fact, to ensure recycling of N in the rumen, OEB has to be negative. As MUN has been shown to have a positive relation with urinary N excretion (Jonker *et al.*, 1998; Kauffman & St. Pierre, 2001) many farmers in the nutrient management project adopted a target of low MUN values of between 9–10 mg dl^{-1}.

Since 1998 milk urea levels have been monitored in the Netherlands. Figure 2.5 shows the results of milk urea content of the farms participating in the project. The figure shows that milk urea content displays strong seasonal fluctuations, with high peaks during the grazing seasons. Over the course of the project this fluctuation decreased, indicating that the farmers improved their control over the milk urea content. This may be due to either better management or lower N-contents of the grass and grass silages. The linear regression line in figure 2.5 indicates an average reduction of milk urea content from 30 mg dl^{-1} at the beginning of the project to 23 mg dl^{-1} at the end (a reduction in terms of MUN from 14 to 11 mg dl^{-1}). According to a formula developed by Kauffman and St. Pierre (2001) this reduction in MUN would imply a reduction of urinary N excretion of 52 g cow^{-1} day^{-1}. Given that 42 farms participated in this experiment, and, assuming an average herd size of 60 milking cows, this implies an annual overall reduction of almost 50 tonnes of urinary N excretion. While this is already a significant reduction, regular contacts with commercial farmers throughout the country and (unpublished) results of APM show that it is possible to achieve MU levels as low as 5 mg dl^{-1} without affecting milk production level or animal health. This shows that there remains a large potential for further increasing N efficiency at animal level.

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[9] Urea is formed from ammonia in the kidney and liver. Ammonia is produced by the breakdown of protein in the rumen and by the ruminant tissues and is very toxic, whereas urea is non-toxic. The conversion of ammonia to urea prevents ammonia toxicity. Urea diffuses readily from blood into milk. It is a normal constituent of milk and the measure of this can be used to estimate the concentration of blood urea. Urea concentrations in blood and in milk are influenced by protein intake, energy intake and urinary excretion.

[10] In the Netherlands milk urea content is used instead of MUN. 1 mg MUN is equal to 2.14 mg urea.

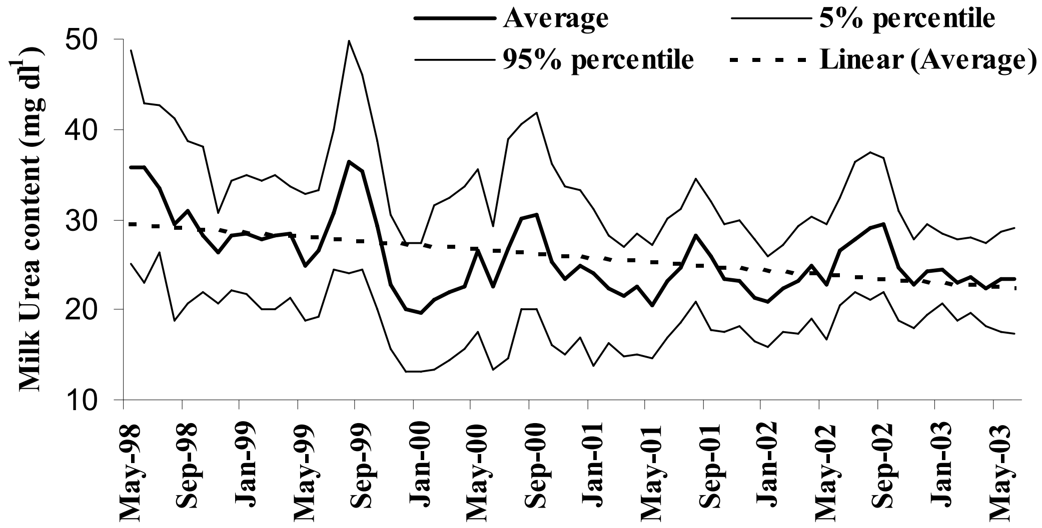

Figure 2.5 *Changes in Milk Urea content (mg dl^{-1}) on VEL and VANLA farms (n=42) during the nutrient management project*

2.4.6 Slurry composition

Several studies have shown that nutrition management can substantially contribute to a reduction in ammonia emissions (Smits *et al.*, 1995; Külling *et al.*, 2001). Phillips *et al.* (1999) reviewed different approaches for reducing ammonia emissions from livestock buildings and identified the best options as 1) dietary manipulation and 2) increasing the C:N ratio by generous use of bedding. These were the two main strategies adopted in the VEL and VANLA project, through which the farmers aimed simultaneously to increase the C:N ratio and to reduce the inorganic N content of their slurry manure. Both strategies aimed to reduce gaseous emissions. Table 2.5 shows the extent to which the farmers succeeded in these aims.

The winter of 1999/2000 was the first period that the project focused on feeding high fibre/low-protein diets. The average inorganic N content of the slurry decreased, while the percentage of organic N and the C:N ratio increased. Most striking is the change in inorganic N, which decreased by 28.6%. These findings are in line with the decreased urinary N excretion suggested in the previous section. According to Erisman (2000) this reduction in inorganic N would imply a considerable reduction of ammonia volatilisation. A good impression of the underlying changes can be obtained from the percentage of farms that produce slurry manure containing less than 50% inorganic N (Table 2.5, last column). In 1996, an average 54% of N in Dutch slurry manure was in inorganic form (Mooij, 1996). In 2002, 93% of the VEL and VANLA farmers had levels below 50%.

Table 2.5 *Slurry manure characteristics (mean ± standard deviation) of the VEL & VANLA-farms in the period 1998–2002 (one sample per farm per winter), in comparison with standard values (Mooij, 1996)*

	n	*DM ($g.kg^{-1}$)*	*OM*[a] *($g.kg^{-1}$ dm)*	*Total N ($g.kg^{-1}$ dm)*	*Inorganic N ($g.kg^{-1}$ dm)*	*% Inorg. N*	*C:N*[b]	*# Farms < 50% Inorg. N*
1998	54	90 ± 19	718 ± 40	52 ± 7	28 ± 8	53 ± 10	7.0 ± 1.0	29%
1999	54	93 ± 24	705 ± 52	54 ± 11	30 ± 10	56 ± 10	6.8 ± 1.4	18%
2000	54	96 ± 14	737 ± 35	51 ± 7	24 ± 7	46 ± 8	7.3 ± 1.1	69%
2001	47	99 ± 20	718 ± 62	50 ± 7	20 ± 6	40 ± 11	7.3 ± 1.1	86%
2002	45	92 ± 15	752 ± 32	47 ± 6	20 ± 5	42 ± 8	8.1 ± 1.2	93%
Mooij(1996)	90		733	54	29	54	6.8	-

a) Organic Matter

*b) The C:N-ratio is calculated as (0.5*OM)/2. The assumption is made that 50% of the organic matter is C.*

Besides reducing gaseous N emissions, changes in manure composition can be expected to induce other effects. When animal manure is used as a fertiliser it has two effects: 1) the short-term release of nutrients and 2) an increase in soil fertility status. These effects are, in turn, a function of the stability of the organic compounds in the manure, which can vary significantly between different manure types. Factors, which influence this include, the type of animal, the way the manure is stored and the composition of the diet. In general, the soluble inorganic fraction in urine is available almost immediately, the gastro-intestinal (endogenous) secretions and microbial matter excreted in the faeces are rapidly degradable and the undigested feed fraction is usually slowly degradable in soil (Velthof *et al.*, 2000). Slurry produced under the feeding strategy adopted by the VEL and VANLA project is likely to contain less soluble inorganic (urinary) N and a more microbial matter, endogenous material and undigested feed. It is anticipated that this will reduce the short-term release of N (Chapter 3) and should make a positive contribution to soil fertility in the longer term.

At the APM, the amount of total N in the top soil layer (0–30 cm) has increased by about 90 kg per ha per year between spring 1996, when the alternative feeding strategy and use of straw as a bedding material was adopted, and spring 2002 (unpublished results). This increase in total soil N should gradually lead to an increase in the soil N supply for plant uptake (Langmeier *et al.*, 2002; Silgram & Chambers, 2002). Furthermore the changed feeding strategy should also reduce the rate of herbage rejection by grazing cattle following slurry manure application and decrease the phytotoxicity of dairy farm slurries (Chapter 3).

2.5 Concluding remarks

The project started with a group of farmers and scientists who were convinced that N losses could be reduced without reductions in production levels or incomes. As described in the first three sections, this hypothesis was inspired by existing heterogeneity in practice, which was assumed to have the common characteristics of achieving a ‘certain balance’ on the farms. By combining local farming practices and specific scientific insights, a toolbox of measures was developed to reduce N losses by improving the balance between different farm subsystems. The proposed feeding strategy was relatively new to most of the farmers and some farmers were initially hesitant about this approach, which appeared to contradict their generally accepted frames of reference. However, during the project quite a few farmers became enthusiastic about this approach and started to experiment with 'the toolbox' on their farms.

In general, the main goals of the project have been achieved. In 2002/2003, 77% of the farmers had achieved the target set by the government for the next growing season. Production levels per hectare were maintained and production per cow increased slightly. A first analysis of economic data from the farms in the project reveals that involvement in the projects substantially contributed to the profitability of the farms (Van der Ploeg *et al.*, 2003). Most of the farmers are convinced that the nutrient management project has had a positive effect on their income. This is illustrated by a quote from one of the VEL and VANLA farmers.

‘Now we are in control of the nutrient cycle, we know that we have spoiled a lot of things for a long time, not only with respect to the nutrients but also financially’.

As expected, the reduction of external inputs and the adoption of the toolbox of measures caused a chain of reactions on the farms. A reduction in fertiliser use was followed by a reduction in the protein content of the silage, changes in the diet composition, milk urea content, manure composition and so forth. In an interview one of the farmers phrased it like this:

‘Less fertiliser use implies other feeding. A few years ago my silage and grass were dark. Now it has become lighter. This has got to do with the nitrogen utilisation, which was far too low, both in the animals and in the soil.’

After 4–5 years of experimenting, reducing inputs, and searching for the right solutions for their specific situation, several farms seem to have reached a new equilibrium. Others are still searching. This new equilibrium can vary quite a lot between farms. In general, farmers are becoming more dependent on their own specific resources and their own management strategies. This implies that the management and skills of the farmer and their knowledge about specific, locally available resources are becoming more important. Increasingly these farmers have to adapt generic solutions relevant to their own specific situation and resources. The Vel and Vanla farmers have followed a variety of strategies that achieved the challenge facing the Dutch dairy sector: that of reducing their N surpluses very rapidly.

In this respect, the VEL and VANLA project can be seen as an example of the potential and importance of the skills and resourcefulness of farmers in harnessing farm specific resources to meet the more stringent new thresholds for N surpluses. The specificity of circumstances such as, soil types, position and size of fields, intensity, farm-size, and the quality of roughage and manure, all demand the development of specific knowledge and solutions. Any increase in the heterogeneity of resource use will have implications on the way in which research for, and advice to, farmers is organised. This new situation requires a greater contextualisation of research and advice services.

The nutrient management project has been successful through 1) combining local and scientific insights into promising practices, 2) implementing these practices at farm level, 3) testing and adapting these practices at farm level and 4) propagating the successful practices. The project has had a large impact on the national, as well as the regional, level. Various forms of knowledge dissemination, including magazines, newsletters, a website, excursions, lectures, courses, conferences and debates in different public media, have spread awareness of the project throughout the country. The characteristic soil-plant-animal-manure-picture has been displayed at local and national meetings about the improvement of nutrient efficiency. Through such activities, the project has been one of the triggers of a growing discussion among scientists, experts and farmers on scientific research methods (Stuiver *et al.*, 2003).

The project has always considered the balance of the production system to be crucial. This balance needs to be created by farmers, moulding their own resources so as to create a coherent whole. The use of multivariate analysis might help to understand some of the complex interactions within these newly emerging patterns (Verhoeven *et al.*, 2003). However, the re-balanced practices that have emerged from these changing production systems, also raises new research questions that require “mono-causal” technical research. For instance: to what extent can feeding strategy influence manure quality? What is the effect of the changed diets on different aspects of animal health? What is the effect of different manure quality, or composition, on grass yields? How to improve soil functioning? What is the effect of different manure types on soil functioning? What is the effect of the use of additives or straw in manure? The VEL and VANLA project cannot provide solid answers to all these questions. Further experiments, under more controlled circumstances, are needed to elucidate the changing mechanisms in this new, re-balanced, soil-plant-animal-manure-system that is running on far lower levels of external inputs than before.

However, answering these questions will not necessarily lead to the development of a sustainable and nutrient efficient dairy-farming sector. System innovation and transition in agriculture has to be based on the innovative work of farmers (Roep *et al*., 2003a). There are many farmers, throughout the Netherlands, making innovative experiments designed to improve nutrient efficiency (Roep *et al*., 2003b). These farmers have developed interesting novelties and often show surprisingly positive results. We argue that the contextualised knowledge that is already available and that has been produced on these farms is essential for any effective transition towards a really sustainable dairy farming. Therefore it is highly important that 1) scientific community comes into (or stays in) contact with these farmers to find solid answers to the complex questions of sustainability and 2) governmental organisations create sufficient 'room for manoeuvre' (Roep *et al*., 2003a) for innovative farmers to continue further development of their promising novelties.

Chapter 3

Explorative research into quality of slurry from dairy farms with different feeding strategies

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Explorative research into quality of slurry from dairy farms with different feeding strategies
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Abstract

To assess cattle slurry quality in relation to feeding strategy, a field experiment and a bio-assay were carried out with slurries from four dairy farming systems that used diets differing in protein content and digestibility. Several quality aspects were evaluated. In the field experiment the effects of slurry type on herbage rejection by grazing heifers and herbage yield on undisturbed plots under cages were studied for a grass monoculture and a grass/clover mixture. The bio-assay, consisting of a cress (Lepidium sativum L.) seed germination test, was used to study differences in phytotoxicity between the slurry types. After five weeks of undisturbed growth at equal amounts of applied inorganic N, the herbage yields differed statistically for the different slurries. This was probably due to immobilization of N in the case of the two slurries from farming systems in which straw was fed and used in the cubicles. Herbage rejection by grazing animals was significantly shown for all slurry types and was significantly and positively correlated with the NH_3/NH_4^+*-N content of the slurry. The slurries showed large differences in phytotoxicity to seeds and seedlings in the bio-assay. The observed phytotoxicity was significantly correlated with the* NH_3/NH_4^+*-content (positive) and the C/N ratio (negative) of the slurries. Phytotoxicity in the cress seed germination test did not account for reduced herbage yields in the field experiment. On the contrary, when the slurries were ranked according to their phytotoxicity the order was the same as the ranking on the basis of undisturbed herbage yield. It was concluded that there is a need for other laboratory tests to assess slurry quality.*

3.1 Introduction

Nutrient efficiency of Dutch dairy farming has decreased drastically during the period 1950–1990, mainly as a result of a strong increase in the use of inorganic fertilizer on grassland (Van Keulen *et al*., 1996). In recent years, European and national legislation have forced farmers to rapidly reduce nutrient losses (Henkens & Van Keulen, 2001). So, there is a need for knowledge on improving nutrient efficiency at farm level. From model calculations Van Bruchem *et al.* (1999a) concluded that the most effective way to reduce N losses at farm level is to improve soil N efficiency by decreasing N input through inorganic fertilizer. This should be accomplished by an improved efficiency of use of internal resources like on-farm produced feed and manure.

Velthof *et al.* (2000) stated that the environmental problems associated with high-input livestock farming systems and inappropriate use of animal manure have given a strong impetus to re-value animal manure as a source of essential plant nutrients and as a means to improve soil quality. Animal manure has to become again the major source of nutrients for fodder crops like grass and maize. Also the farmers of the VEL and VANLA environmental co-operatives in the province of Friesland recognized this need as crucial and aim at an improvement of slurry through an adapted feeding strategy (Stuiver *et al*., 2003).

Recently, attempts have been made at the integrated mixed farm A.P. Minderhoudhoeve (APM) in Oostelijk Flevoland to modify slurry quality by means of adapting feeding strategy (Lantinga, 2000). To reduce ammonia emission and nitrate leaching, to stimulate microbiological activity in the soil and to increase soil organic N content, dietary crude protein content was decreased drastically and up to 3 kg straw per cow was fed daily. In the farm's grass/clover leys the amount of total N in the 0–30 cm soil layer increased with 250 kg N ha^{-1} year^{-1} on average (unpublished results). This high net immobilization of soil N was attributed to the high C/N ratio of the slurry applied (cf. Whitehead, 1995). In addition, also the use of straw as animal feed or bedding material can cause immobilization (Van Faassen & Van Dijk, 1987). An increase in total soil N may lead to an increase in the inorganic soil N supply available for plant uptake (Langmeier *et al*., 2002; Silgram & Chambers, 2002).

Herbage rejection due to fouling by cattle is a phenomenon frequently observed in pasture studies. Generally, the odour of the faeces is thought to be the main reason for herbage rejection around dung pats (Marten & Donker, 1964; Marsh & Campling, 1970; Dohi *et al*., 1999). The botanical composition of the sward may influence the degree of rejection. Marten & Donker (1964) found that faeces deposited on a monoculture of bromegrass led to greater refusal of forage than faeces deposited on a mixture of bromegrass and alfalfa. According to Mackie *et al.* (1998) there are four principal classes of odour compounds: (1) branched- and straight-chain volatile fatty acids (VFA),

(2) ammonia and volatile amines, (3) indoles and phenols, and (4) volatile sulphur-containing compounds. These compounds are products from hydrolysis and fermentation of organic matter under anaerobic conditions. At the APM farm, Bosker *et al.* (2002) found considerably less herbage rejection around dung pats from cattle fed a low-protein diet that included straw than around dung pats from cattle fed diets without straw. Besides, slurry produced on this diet and applied on a continuously grazed pasture did not lead to herbage rejection.

Phytotoxic properties of organic substances can severely damage crop yields (Mathur *et al.*, 1993). A relatively easy andquick method to test phytotoxicity of chemical substances is a bio-assay, using a germination test with cress (*Lepidium sativum* L.) seeds. This test is often used to evaluate toxicity of organic fertilizers like compost (Zucconi *et al.*, 1985). Phytotoxicity in such a seed germination bio-assay is the capability of substances to inhibit or reduce seed germination or root growth. From a bio-assay with cress seeds, using the same dung types as Bosker *et al.* (2002), Hoekstra *et al.* (2002) concluded that diets with lower protein contents and less supplementary concentrates resulted in a lower phytotoxicity of the dung to seeds or seedlings. The highest negative correlations were found between the germination index (a combined and dimensionless index for the number of germinated seeds and the root length of the germinated seeds, relative to the control) and electric conductivity (EC) or total-N concentration in the dung extracts. The authors suggested that slurry might be more phytotoxic than dung because of its much higher ammonia content, which is known for its phytotoxicity to seeds and seedlings (Wong *et al.*, 1983). Van Bruchem *et al.* (1999b) suggested that besides ammonia, also other nitrogenous compounds resulting from amino-acid metabolism, like biogenic amines and phenolic compounds (phenol, indol, scatol, cresol) might play a role in phytotoxicity.

In this study, slurries collected from four farming systems with different feeding strategies were compared in a field experiment and a bio-assay using the cress germination test. The objectives of the field experiment were to determine (1) effects of the four slurries on apparent N recovery and herbage yield with undisturbed growth of a grass/clover field and a grass monoculture, (2) whether these effects could be related to the amount of inorganic N applied, (3) whether these effects could be related to the diet of the animals from which the slurry was obtained or to slurry characteristics, (4) effects of these manures on herbage rejection in a grass/clover mixture and a grass monoculture, and (5) whether these rejection effects could be related to odorous compounds in the slurry.

The objectives of the bio-assay were to determine (1) whether there are differences in phytotoxicity between the slurry types, and (2) whether these differences could be related to chemical characteristics of the slurry. The objective of the combination of the two experiments was to test whether the differences in phytotoxicity as established in the bio-assay could be related to yield differences observed in the field experiment.

3.2 Materials and methods

3.2.1 Slurry collection, storage and sampling

The experiments were carried out in the summer of 2001 with slurry from four farming systems (laid out at three different experimental farms) with different feeding strategies (Table 3.1). APMlac slurry was from lactating cows at experimental farm A.P. Minderhoudhoeve (APM). The diet fed to these cows had a moderate protein content and was rather low in digestibility because of the addition of straw. OSK slurry was collected from experimental farm De Ossekampen in Wageningen, where dairy cows were fed highly digestible fresh grass with a high protein content. APMdry slurry was from dry cows at experimental farm APM, which were fed a low-protein diet including straw with low digestibility. MAR slurry was from dairy cows of experimental farm De Marke in Hengelo (Gelderland), where the cows were fed a highly digestible diet with a moderate protein content.

From each farming system 800–900 litres of slurry were collected and mixed in a 1000-litre polyethylene container. The APMlac and APMdry slurries were collected with a manure scraper from a concrete floor, filling the containers by hand. The OSK and MAR slurries were pumped directly from the slurry pit into the containers (Table 3.1). Containers were stored outdoors for 2 to 3 weeks. On 13 August 2001, after mixing the slurry in the application unit shortly before use, a sample from each slurry type was taken and analysed for dry matter (ISO 6496) and total-N (Kjeldahl method, ISO 5983) (Table 3.2). Ash was determined in a furnace at 550 °C. Total C of the slurry samples was determined by elemental analysis using an EA 1110 CHN analyser (CE instruments, Milan, Italy). NH_3/NH_4^+-N was determined according to the Berthlot method (Anon., 1974) (Table 3.2). NH_3/NH_4^+-N is the sum of NH_3 (aq) and NH_4^+ present in the equilibrium: $NH_3 \text{ (aq)} \Leftrightarrow NH_4^+ + OH^-$, with NH_3 (aq) being the amount of NH_3 dissolved in water.

To determine biogenic amines, phenol, indol, cresol and scatol contents, 1 gramme slurry was extracted with 1ml methanol during 4 hours at room temperature. The extract was centrifuged at 3000 × *g* and the supernatant was used for further analysis. Biogenic amines were separated with ion-chromatography, using an amino acid analyser (Alpha Plus®, LKB, Sweden). Determination was done using spectophotometry at 570 nm after post-column colouring with ninhydrin. For the determination of phenol the supernatant was analysed with reversed phase chromatography using a C-18 Alltime® column. The eluent consisted of 50% Na-acetate (2.5 g l^{-1}) and 50% methanol. Peak registration was done with UV-detection at 275 nm.

The same methods were used for the determination of cresol, indol and scatol, using a slightly different eluent (35% Na-acetate and 65% methanol) and peak registration for cresol and indol at 215 nm and for scatol at 223 nm.

Table 3.1 *Intake, diet composition and other characteristics of the four farming systems where cattle slurry was collected*

	Farming system where slurry was collected[a]			
	APMlac	*OSK*	*APMdry*	*MAR*
Intake (kg DM[b] *cow*$^{-1}$ *day*$^{-1}$*)*				
Grass silage			5.2	1.2
Maize silage				6.8
Whole-crop wheat silage	6.9		2.2	
Fresh grass	7.0	13.9		6.3
Wheat straw	1.5		1.8	
Maize straw				0.9
By-products	3.4			2.3
Concentrates	3.1	2.6	1.5	4.4
Total	21.8	16.5	10.7	22.1
Diet composition				
VEM (kg^{-1} DM)	930	1050	820	1020
Crude Protein (g kg^{-1} DM)	141	180	120	149
Starch (g kg^{-1} DM)	101	27	73	194
Other characteristics				
Bedding material	chopped straw	sawdust	chopped straw	sawdust
Collected from	floor	pit	floor	pit
Time between production and collection	0 weeks	1 week	0 weeks	4 weeks
Time between collection and application	3 weeks	2 weeks	3 weeks	2 weeks

a) APMlac = A.P. Minderhoudhoeve (lactating cows); OSK = Ossekampen; APMdry = A.P. Minderhoudhoeve (dry cows); MAR = De Marke

b) DM = dry matter

c) VEM = Voeder Eenheid Melk, Dutch standard for Net Energy Lactation (1VEM = 6.9 kJ)

3.2.2 The field experiment

The field experiment was laid out on a 3.2-ha pasture of experimental farm De Ossekampen. The soil was a fine-textured river clay with 53% lutum (particles < 0.002 mm), 8.1% organic matter (C/N ratio 7) and pH-KCl 5.0 in the 0–10 cm soil layer. The pasture had been established in June 1999, after one year of cropping with silage maize (*Zea mays* L.).

The area where the experiment was carried out, consisted of an experimental part and a put-and-take part. Herbage height on the experimental part was controlled by exchanging heifers with the put-and-take part. The average herbage height aimed at was 7 cm, being the optimum height under continuous grazing in terms of both herbage intake per animal and per unit area (Lantinga, 1988). Half of the experimental part (grass/clover) was sown with a mixture of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), the other half (grass) with perennial ryegrass only. Before the start of the experiment three silage cuts were taken on the entire field. Before every cut, the field was fertilized at a rate of about 150 kg inorganic fertilizer N per ha in total. After the first cut 25 m^3 slurry per ha was applied, equivalent to an amount of 110 kg total-N per ha.

On the grass/clover as well as on the grass of the experimental part 20 plots of 2.4 m × 10 m were established. On 13 August 2001, 10 days after the third silage cut, the different slurry types were surface-applied on these plots in small strips, using a Schepan MMM® slurry application unit (Scheepers, 1978). Surface application was used to be able to study the rejection of fouled herbage. The intention was to apply 80 kg total N ha^{-1} for each slurry type. The actual amount applied varied between 71 and 82 kg total N ha^{-1}. On the control plots (no-slurry), 25 m^3 water ha^{-1} was applied.

To study the effect of slurry on undisturbed herbage growth, cages covering an area of 3.75 m × 1.05 m were placed in the centre of 10 plots in each half of the experimental part. The remaining 10 plots were used to study the effect of slurry on herbage rejection by grazing heifers. On both grass and grass/clover there were two replications of each treatment combination. Caged plots and grazed plots were randomized within sub-blocks. After the application of the four slurries, 17 pregnant heifers were given access to the experimental part, having a free choice between grass and grass/clover. Thereafter the number of heifers was adjusted according to the average herbage height in the grazed area of the experimental plot. Herbage height was measured on each plot, using a falling plate meter with a diameter of 50 cm and a weight of 435 g. Recordings were taken at weekly intervals, starting immediately after slurry application. The faeces from the heifers grazing on the experimental plots were removed daily by hand, using a small shovel.

On 14 September 2001, because of persistently wet conditions, the field experiment was terminated. From the centre of each plot a strip of herbage was harvested using a reciprocating motor mower with a working width of 1.00 m, leaving a stubble height of about 4 cm. Patches where the fouled grass could not be cleaned satisfactorily, were not harvested. This implied that the length of the harvested strips varied. For the caged plots the length of the strips was equal to the length of the cage, i.e., 3.75 m. Harvested material was dried, weighed and sampled. Samples were analysed for (1) dry matter, after drying at 103 °C, (2) ash, by combustion in a furnace at 550 °C, (3) total N and total-C, using a CE Instruments EA 1110® CHN analyser, (4) neutral-detergent fibre (NDF) according to Van Soest *et al.* (1991), and (5) water-soluble carbohydrates (WSC) by extraction with 80% ethanol at 80 °C for 20 minutes, drying the extract, re-desolving it in water, and analysing the solution with a Dionex HPAEC® system.

Because of possible contamination with soil due to the wet weather conditions, herbage organic matter yield (HOM) was used as the indicator for yield instead of dry matter yield. N use efficiency of the herbage on the caged grass plots was expressed as apparent N recovery (ANR), according to Van der Meer *et al.* (1987):

$$ANR = \frac{(DM\ yield \times herbage\ N\ content)_{slurry\ treated} - (DM\ yield \times herbage\ N\ content)_{control}}{N\ applied\ with\ slurry} \times 100 \quad (3.1)$$

where DM yield and amount of N applied with slurry are expressed in kg ha^{-1}.

ANR could not be calculated for the grass/clover plots due to the unknown contribution of N_2-fixation by the clover. On the grazed plots the change in herbage height during the first week (CHH) was used as the main indicator of herbage rejection, by comparing the manured plots with the control. The difference in HOM yield between the manured plots and the control, at the end of the experiment, was used as an additional indicator for rejection.

3.2.3 Bio-assay

The bio-assay to study possible phytotoxicity effects of the slurries consisted of the cress seed germination test. For this test the dry matter content of the four slurry samples was standardized at 5% by adding water and shaking the mixture for 15 hours in the dark at room temperature (Paré *et al.*, 1997). The mixtures were centrifuged at 2700 × *g* for 20 minutes after which the supernatant was again centrifuged for 15 minutes. This supernatant was used in the bio-assay as the undiluted extract of the slurry. As not much was known about the phytotoxicity level of the slurries, three different dilutions were made of the undiluted extract: 1.0, 0.5 and 0.1%. Concentrations of water-extractable Cu, Zn and Cd were determined in the supernatant by Inductively Coupled Plasma-Mass Spectrometry, with the Elan 6000®, following the shaking of dried slurry with water (1:20 w/w) for 2 hours (Table 3.2). EC and pH and were measured in all extracts (Table 3.2).

The germination test was carried out in an non-illuminated growth cabinet at a constant temperature of 24 °C and relative humidity of 90%. The experiment was of a randomized complete block design with 3 × 2 blocks divided over 3 cabinet shelves. A block comprised 17 treatments: 4 slurry types × 4 extract concentrations, plus a control. For the control demineralized water was used. An experimental unit consisted of 10 cress seeds placed in a 9-cm petri dish with five layers of filter paper (Schleicher & Schuell No 595, 85 mm rundfilter) onto which 5 ml of slurry extract or demineralized water were placed (Paré *et al.*, 1997). Percentage germination was recorded after 24, 48 and 72 hours of incubation. A visible root was used as the operational criterion of germination. After 72 hours the length of the roots was measured. Relative seed germination (RSG) after 24 (RSG-24), 48 (RSG-48) and 72 (RSG-72) hours and relative root growth (RRG) and germination index (GI) after 72 hours of exposure to slurry.

$$RSG\ (\%) = \frac{\text{no. of seeds germinated with slurry extract}}{\text{no. of seeds germinated with water}} \times 100 \qquad (3.2)$$

$$RRG\ (\%) = \frac{\text{mean root length with slurry extract}}{\text{mean root length with water}} \times 100 \qquad (3.3)$$

$$GI = \frac{RSG \times RRG}{100} \qquad (3.4)$$

3.2.4 Statistical analyses

The field experiment was analysed separately for caged and non-caged plots with analysis of (co-)variance in SPSS (Anon., 2001). In the final analyses only the main effects of slurry type and field (grass/clover or grass) were included. In the analysis of HOM yields initial herbage height was used as a co-variable for both the caged and the grazed plots. Differences between slurry types within fields were tested with the Tukey test. Pearson's method was used to calculate correlation coefficients, using mean values of the results.

In the cress germination test the effects of slurry type, concentration and shelf position in the growth cabinet on RSG, RRG and GI were analysed using Analysis of Variance in a full factorial model (Anon., 2001). Pearson correlation coefficients were calculated between RSG, RRG and GI on the one hand and slurry characteristics on the other.

3.3 Results

3.3.1 Slurry analysis

The slurry analysis yielded some unexpected results (Table 3.2). C/N ratios of the slurries were relatively high and ranged from 8.9 for APMlac to 15.5 for APMdry slurry. Total-N content of OSK slurry, the slurry that originated from cows on a diet with the highest crude protein content (180 g per kg DM), was lower than expected. A possible explanation for this low total-N content is that the ratio between faeces and urine in this slurry sample was too high compared with the original slurry due to insufficient mixing. This explanation is supported by the low content of ash, which is mainly excreted with urine, for OSK slurry compared with the other slurries (Table 3.2).

Table 3.2 *Composition of the cattle slurries used in the study*

		Farming system where slurry was collected[a]			
		APMlac	*OSK*	*APMdry*	*MAR*
Slurry (before application)					
DM[b] (g kg^{-1})		56	86	113	88
Total-N (g kg^{-1} DM)		47	33	28	43
NH$_3$/NH$_4^+$-N (g kg^{-1} DM)		27	16	10	24
C:N-ratio		8.9	14.4	15.5	10.2
Ash (g kg^{-1} DM)		249	191	244	284
Phenol (mg kg^{-1} DM)		0.14	0.09	0.07	0.13
Cresol (mg kg^{-1} DM)		n.d. [c]	n.d.	n.d.	n.d.
Indol (mg kg^{-1} DM)		0.02	0.02	0.01	n.d.
Scatol (mg kg^{-1} DM)		0.45	0.37	0.04	0.22
Supernatant (before germination test)					
Putrescine (mg l^{-1})		0.33	0.17	0.45	0.68
Histamine (mg l^{-1})		n.d.	n.d.	n.d.	n.d.
Cadaverine (mg l^{-1})		n.d.	n.d.	n.d.	n.d.
Tyramine (mg l^{-1})		n.d.	n.d.	n.d.	n.d.
Cu (mg l^{-1})		0.36	0.08	0.43	0.68
Zn (mg l^{-1})		0.73	0.19	0.93	1.43
Cd (mg l^{-1})		0.26	0.13	0.25	0.20
Extracts (before germination test)					
	Conc. (%)				
pH	5% (undiluted)	7.60	7.54	7.58	7.99
	1%	7.84	7.63	7.86	8.02
	0.5%	7.93	7.63	7.83	8.00
	0.1%	7.93	7.61	7.86	7.99
Electrical conductivity (mS cm^{-1})	5% (undiluted)	13.7	7.7	9.5	13.8
	1%	4.4	2.2	2.1	3.4
	0.5%	2.3	1.2	1.0	1.7
	0.1%	0.2	0.0	0.0	0.2

a) APMlac = A.P. Minderhoudhoeve (lactating cows); OSK = Ossekampen; APMdry = A.P. Minderhoudhoeve (dry cows); MAR = De Marke
b) DM = dry matter
c) n.d. = not detectable

On the other hand, total-N and NH$_3$/NH$_4^+$-N content (57% of total N) of APMlac slurry were somewhat higher than expected (Table 3.2). Regular slurry analyses at APM in the summer of 2000 showed an average C/N ratio of 9.1 and a total-N content of 41 g per kg DM of which 50% was present as NH$_3$/NH$_4^+$-N. In the winter of 2000 the adapted feeding strategy at APM led to a much lower N content of the slurry, with a total-N content of 29 g per kg DM - of which only 38% was present as NH_3/NH_4^+-N - and a C/N ratio of 13.3 (unpublished data). The higher N values and lower C/N ratio in our study can probably be explained by a high protein content in the grazed grass/clover sward at the time of slurry collection. Because of these unexpected values, the range of total-N content and C/N ratio of the slurries was not as wide as intended.

The contents of phenolic compounds in the slurries were low (Table 3.2). Cresol could not be detected. Phenol ranged from 0.07 to 0.14 mg per kg DM and scatol from 0.04 to 0.45 mg per kg DM. Indol was hardly detectable and its content ranged from non-detectable to 0.02 mg per kg DM. Of the biogenic amines analysed in the supernatant, only putrescine could be detected in small concentrations. Its content was highest in the MAR and lowest in the OSK slurry extract. EC was lower for the OSK and APMdry than for the APMlac and MAR slurry extracts. NH_3/NH_4^+-N content was highly correlated with both phenol content and EC of all slurry extracts. The contents of putrescine, Zn and Cu were also strongly mutually correlated.

3.3.2 Field experiment

Caged plots

The effects of the slurry types on HOM yield, total-N content of the harvested material and ANR for the grass after 5 weeks of undisturbed growth are summarized in Table 3.3. Mean response of HOM yield to MAR slurry was significantly higher than to APMlac and APMdry slurry and to no slurry (control). On the grass/clover plots, MAR and OSK slurry led to significantly higher HOM yields than APMdry slurry and no slurry. For the grass plots no statistically significant differences in (HOM) yield between slurry types were found. However, when ranking the slurry types in terms of their effects on HOM yield the order was the same as found for the grass/clover plots: MAR > OSK > APMlac > APMdry.

The amount of NH_3/NH_4^+-N applied per ha was 40.6, 40.7, 41.4 and 27.7 kg ha^{-1} for APMlac, OSK, MAR and APMdry slurry, respectively. Although similar amounts of NH_3/NH_4^+-N were applied with the first three slurries, there were statistically significant differences in HOM yield between APMlac and MAR slurry (Figure 3.1).

Total-N content of the harvested material varied between 21.3 and 40.6 g per kg OM. No statistically significant differences in total-N content between slurry types were found (Table 3.3). WSC contents of the harvested material were very low (< 7 g per kg OM). The differences in WSC and NDF content of the harvested material between slurry types were not statistically significant (data not shown). The two measurements of ANR (only grass plots) did not show any statistically significant difference between slurry types (Table 3.3). However, ANR tended to be higher ($P = 0.052$) for MAR slurry than for APMlac slurry. The ANR for both slurries from APM were even negative. No statistically significant correlation was found between ANR or HOM yield and any of the slurry characteristics.

Table 3.3 *Herbage organic matter (HOM) yield, total-N content and apparent N recovery (ANR) of grass/clover and grass after 5 weeks of undisturbed growth on plots fertilized with different types of slurry (Means ± standard error)*

	Slurry type^{a}					
	APMlac	*OSK*	*APMdry*	*MAR*	*No slurry*	*Mean*
HOM yield^{bc} *(kg ha*$^{-1}$*)*						
Grass/clover	2383 ± 129 *ab*	2589 ± 107 *b*	2188 ± 110 *a*	2529 ± 114 *b*	2338 ± 107 *a*	2405 ± 113
Grass	1703 ± 114	2098 ± 108	1673 ± 122	2213 ± 110	1835 ± 113	1904 ± 114
Mean	2043 ± 121 *a*	2343 ± 108 *ab*	1930 ± 116 *a*	2371 ± 112 *b*	2087 ± 110 *a*	2155 ± 113
Total-N (g kg^{-1} *OM*^{d}*)*						
Grass/clover	36.3 ± 0.4	35.6 ± 1.7	37.6 ± 2.3	35.0 ± 1.2	36.9 ± 0.2	37.2 ± 0.6
Grass	22.6 ± 0.1	26.4 ± 1.3	24.2 ± 0.1	22.8 ± 0.3	22.5 ± 1.2	24.5 ± 0.7
Mean	29.4 ± 4.0	31.0 ± 2.8	30.9 ± 4.0	28.9 ± 3.6	29.7 ± 4.2	30.9 ± 1.5
ANR (kg kg^{-1}*)*						
Grass	–0.04 ± 0.04	0.18 ± 0.06	–0.01 ± 0.07	0.25 ± 0.03	n.a.^{e}	0.09 ± 0.05

a) Acronyms refer to the farming systems where the slurry was collected. See Table 3.1.
b) HOM yields corrected for initial herbage height
c) Mean yields in the same row, followed by a different letter are statistically different ($P < 0.05$).
d) OM = Organic Matter
e) n.a. = not available

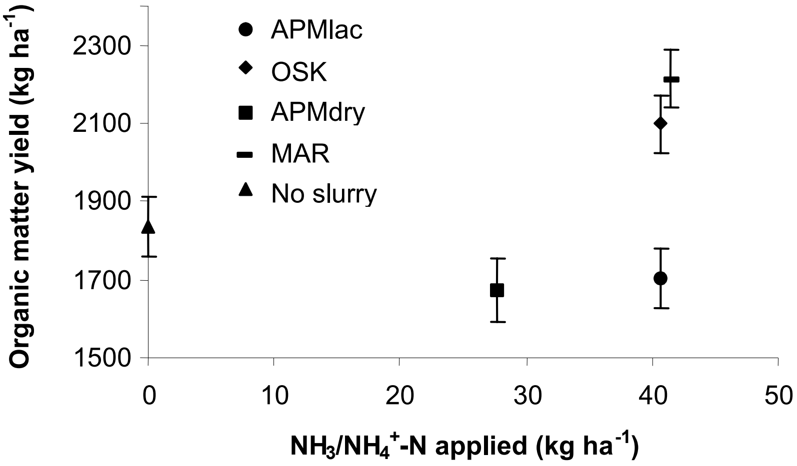

Figure 3.1 *Relationship between amount of NH_3/NH_4^+-N applied with cattle slurry and corrected organic matter yield for grass plots fertilized with different types of slurry*

Grazed plots

The changes in herbage height after one week (CHH) and HOM yields after 5 weeks of grazing are summarized in Table 3.4. Mean CHH for all slurry-treated plots was significantly higher than mean CHH for the no slurry plots. MAR slurry led to a significantly higher CHH than APMdry slurry, whereas the two other slurries had intermediate values. The ranking order of the four slurries for CHH was MAR > APMlac > OSK > APMdry. Both, the grass and the grass/clover plots showed the same ranking order.

Table 3.4 *Herbage organic matter (HOM) yield after 5 weeks and change in herbage height after 1 week (CHH) on grazed grass/clover plots fertilized with different types of cattle slurry (Means ± standard error)*

	Slurry type[a]					
	APMlac	*OSK*	*APMdry*	*MAR*	*No slurry*	*Mean*
HOM yield[bc] *(kg ha^{-1})*						
Grass/clover	334±0.6 ab	407±2.6 b	299±1.2 ab	434±0.6 ab	176±3.1 ab	330±30.3
Grass	508±0.4	586±2.5	469±2.4	611±2.0 ab	349	522±28.3
Mean	412±50.5 bc	496±57.0 bc	384±56.4 ab	522±52.6 c	234±60.8 a	421±55.2
CHH (cm)						
Grass/clover	–0.23±0.02 ab	–0.30±0.50 ab	–0.53±0.33 ab	0.55±0.30 b	–2.17±0.33 a	–0.53±0.32
Grass	0.03±0.13	–0.15±0.80	–0.30±0.25	0.60±0.10	–0.67±0.13	–0.10±0.19
Mean	–0.10±0.09 bc	–0.23±0.39 bc	–0.41±0.18 b	0.58±0.13 c	–1.43±0.46 a	–0.32±0.19

a) Acronyms refer to the farming systems where the slurry was collected. See Table 3.1.
b) HOM yields corrected for initial herbage height
c) Mean yields in the same row, followed by a different letter are statistically different (P < 0.05)

For the grass/clover plots CHH was positively and significantly correlated with the NH$_3$/NH$_4^+$-N content of the slurry ($R^2 = 0.98$, $P < 0.05$, n = 4). Also for the grass plots this correlation was statistically significant ($R^2 = 0.98$, $P < 0.05$, n = 4).

HOM yield for the grazed plots at the end of the 5-week grazing period, the second indicator of herbage rejection, showed almost the same ranking order of the slurries as the first indicator, CHH: MAR > OSK > APMlac > APMdry. Only APMdry slurry gave no significantly higher mean HOM yield than the control plots. None of the slurry characteristics appeared significantly correlated with HOM yield after 5 weeks of grazing.

3.3.3 Bio-assay

Relative seed germination

The effects of slurry type and extract concentration and the slurry × extract concentration interaction on relative seed germination (RSG) were statistically highly significant ($P < 0.001$). The undiluted extracts of APMlac, OSK and MAR slurries completely inhibited germination while some germination took place with APMdry slurry (Table 3.5). With an extract concentration of 1% there were large differences in RSG after 24 hours (RSG-24) between the slurries. The ranking order of the slurries for their effect on RSG-24, RSG-48 and RSG-72 was APMdry > OSK > APMlac > MAR. RSG-24 was significantly higher with APMdry and OSK slurry than with the two other slurries. With a RSG-48 of 91.7 the inhibiting effect of APMlac slurry seems only to have been a delay, whereas MAR slurry had a permanent inhibiting effect, as is illustrated by a significantly lower RSG-48 and RSG-72 for this slurry than for the other ones. No statistically significant differences between the effects of the slurries were found at an extract concentration of 0.5%. With a concentration of 0.1%, seed germination was hardly inhibited. However, RSG-48 and RSG-72 were significantly lower with OSK slurry than with the other slurries.

Relative root growth and germination index

The effects of slurry type and extract concentration on relative root growth (RRG) and germination index (GI) and the interaction slurry type × extract concentration were statistically highly significant ($P < 0.001$). The undiluted extract of APMdry slurry was the only one that did not inhibit germination completely, resulting in a statistically significantly higher RRG and GI than for the other slurries (Table 3.5). As to the other extract concentrations, the ranking order of the slurries was the same for both RRG and GI: APMdry > OSK > APMlac > MAR (Table 3.5). In contrast to an extract concentration of 0.1%, the differences in RRG and GI between slurries at concentrations of 1% and 0.5% were statistically significant (Table 3.5).

Table 3.5 *Results of the bio-assay. Effects of extract concentration of the different cattle slurries on relative seed germination (RSG) after 24, 48 and 72 hours, root length, relative root growth (RRG) and germination index (GI)[a] (Means ± standard error)*

Extract conc./	RSG after …. Hours			Root length	RRG	GI
Slurry type[b]	24	48	72	(mm)		
5 percent (undiluted)[c]						
APMlac	0.0 ± 0.0	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*
OSK	0.0 ± 0.0	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*
APMdry	3.5 ± 2.2	25.0 ± 8.5*b*	36.7 ± 6.7*b*	2.7 ± 0.9*b*	5.8 ± 1.8*b*	2.6 ± 1.0*b*
MAR	0.0 ± 0.0	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*	0.0 ± 0.0*a*
1 percent[c]						
APMlac	17.5 ± 5.9*a*	91.7 ± 3.1*b*	95.0 ± 3.4*b*	7.4 ± 1.1*ab*	15.7 ± 2.3*ab*	14.5 ± 1.5*ab*
OSK	91.2 ± 3.5*b*	95.0 ± 2.2*b*	96.7 ± 2.1*b*	10.2 ± 1.8*b*	21.8 ± 3.9*b*	21.2 ± 3.9*b*
APMdry	103.5 ± 1.8*b*	98.3 ± 1.7*b*	98.3 ± 1.7*b*	39.4 ± 2.6*c*	83.9 ± 5.6*c*	82.1 ± 4.4*c*
MAR	3.5 ± 2.2*a*	41.7 ±11.7*a*	45.0 ±12.0*a*	1.9 ± 1.1*a*	4.0 ± 2.3*a*	3.1 ± 2.4*a*
0.5 percent[c]						
APMlac	80.7 ± 8.0	95.0 ± 3.4	96.7 ± 3.3	20.2 ± 2.9*b*	42.8 ± 6.1*b*	42.1 ± 6.6*b*
OSK	94.7 ± 3.8	95.0 ± 3.4	98.3 ± 1.7	38.6 ± 2.7*c*	82.0 ± 5.8*c*	80.7 ± 6.0*c*
APMdry	96.5 ± 1.8	93.3 ± 2.1	93.3 ± 2.1	49.7 ± 3.0*d*	105.6 ± 6.4*d*	98.8 ± 7.0*c*
MAR	86.0 ± 4.2	95.0 ± 2.2	96.7 ± 2.1	8.4 ± 0.9*a*	17.9 ± 2.0*a*	17.5 ± 2.2*a*
0.1 percent[c]						
APMlac	105.3 ± 0.0	100.0 ± 0.0*b*	100.0 ± 0.0*b*	41.5 ± 3.0	88.2 ± 6.3	88.2 ± 6.3
OSK	100.0 ± 3.6	95.0 ± 2.2*a*	95.0 ± 2.2*a*	44.1 ± 2.8	93.8 ± 5.9	89.2 ± 6.3
APMdry	105.3 ± 0.0	100.0 ± 0.0*b*	100.0 ± 0.0*b*	46.3 ± 2.4	98.4 ± 5.2	98.4 ± 5.8
MAR	96.5 ± 3.2	100.0 ± 0.0*b*	100.0 ± 0.0*b*	39.9 ± 1.9	84.9 ± 4.1	84.9 ± 4.1
Control[d]	100.0 ± 3.6	100.0 ± 0.0	100.0 ± 0.0	47.0 ± 3.4	100.0 ± 7.0	100.0 ± 7.0

a) For an explanation of the different germination parameters see text
b) Acronyms refer to the farming systems where the slurry was collected. See Table 3.1
c) Means in a column within the same concentration, followed by a different letter are statistically different ($P < 0.05$)
d) Demineralized water

Correlation coefficients

With the undiluted slurry extracts, NH_3/NH_4^+-N was the only slurry parameter that was significantly and negatively correlated with RSG-24. All nitrogenous parameters, i.e., total N, NH_3/NH_4^+-N, ammonia, phenol, indol and scatol contents, were significantly and negatively correlated with RRG (Table 3.6). With an extract concentration of 1%, all slurry parameters except Cd were significantly and negatively correlated with RSG-24. The highest and statistically most significant correlations were found with ammonia, EC, NH_3/NH_4^+-N, total N, phenol and indol contents (Table 3.6). With a concentration of 1%, RRG was significantly correlated with ammonia, EC,

NH_3/NH_4^+-N, total N, phenol, indol and scatol contents, of which the correlations with ammonia, NH_3/NH_4^+-N, total N and indol contents were highly significant.

With a concentration of 0.5%, only EC, ammonia, NH_3/NH_4^+-N, total N and phenol contents were significantly and negatively correlated with RSG-24. All characteristics except Cd and scatol contents were significantly and negatively correlated with RRG. Among them, the correlations with ammonia, pH, EC, NH_3/NH_4^+-N, total N and indol contents were highest and statistically most significant (Table 3.6). As no statistically significant differences in RSG-24 and RRG were found with the 0.1% slurry extracts, correlation coefficients for this concentration are not shown.

Table 3.6 *Results of bio-assay. Correlation coefficients (R^2) between relative seed germination after 24 hours (RSG-24) and relative root growth (RRG)^a on the one hand and cattle slurry parameters on the other, at different slurry extract concentrations*

Slurry parameter	*Extract concentration*					
	5 percent		*1 percent*		*0.5 percent*	
	RSG-24	*RRG*	*RSG-24*	*RRG*	*RSG-24*	*RRG*
pH	0.03	0.06	0.41 **	0.01	0.12	0.45 ***
EC	0.04	0.08	0.74 ***	0.36 **	0.24 **	0.52 ***
Ammonia	0.14	0.18 *	0.46 ***	0.90 ***	0.77 ***	0.23 *
NH_3/NH_4^+-N	0.18 *	0.41 **	0.83 ***	0.71 ***	0.23 *	0.77 ***
total-N	0.15	0.34 **	0.87 ***.	0.61 ***	0.24 *	0.72 ***
Cu	0.00	0.01	0.36 **	0.00	0.04	0.29 **
Zn	0.01	0.01	0.32 **	0.00	0.03	0.27 **
Cd	0.05	0.12	0.06	0.13	0.04	0.00
Putrescine	0.00	0.01	0.28 **	0.01	0.02	0.25 *
Phenol	0.12	0.26 *	0.59 ***	0.40 **	0.23 *	0.42 **
Indol	0.05	0.45 **	0.77 ***	0.77 ***	0.08	0.76 ***
Skatol	0.06	0.30 **	0.23 *	0.36 **	0.01	0.15

a) For an explanation of the germination parameters RSG and RRG see text
*b) Statistically significant (n = 24). * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$*

3.4 Discussion

3.4.1 Field experiment

Caged plots

Despite statistically significant differences in HOM yield between slurry types, no statistically significant effect of slurry type on ANR was found, which was due to the low number of replications (only two) and the large variation. Furthermore, no relation was found between HOM yield and amount of inorganic N applied with the slurries.

Although this amount was the same for three of the four slurry types (APMlac, OSK and MAR), the differences in HOM yield between these slurries were statistically different. HOM yield was highest with MAR and lowest with APMlac slurry. We assume that the differences in HOM yields in this experiment were caused by a net immobilization of N with slurries APMlac and APMdry, reflected by the negative ANR values of these slurries and their lower HOM yields in comparison with the no slurry plots.

An immobilizing effect of manure can be caused by feeding low digestible feed components (Kyvsgaard *et al.*, 2000). Furthermore, straw addition can cause net N immobilization in the short run, probably by its stimulating effect on the transformation of C derived from faeces, urine and soil (Van Faassen & Van Dijk, 1987; Sørensen, 1998). APMlac and APMdry slurry, which had the lowest ANR values and showed lowest HOM yields, were from farming systems where 1.5–1.8 kg straw cow^{-1} day^{-1} was included in the diet (Table 3.1). This straw has been the main cause of a lower digestibility of these diets. Moreover, these farms also added approximately 1 kg of chopped straw cow^{-1} day^{-1} to the slurry through its use as bedding material. We therefore conclude that the addition of straw, both in the form of diet and as bedding material, is the main factor determining the low HOM yields with APMdry and APMlac slurry in the short period of our experiment. However, from a long-term experiment Silgram & Chambers (2002) concluded that the addition of straw contributes to the soil N supply in the longer run.

Herbage rejection

Under grazing, the effect of slurry is two-sided. Beside a stimulating effect on herbage growth, slurry can cause herbage being rejected by the animals (Garstang & Mudd, 1971). The two indicators used in our study for the rejection of herbage, i.e., change of herbage height after one week (CHH) and HOM yield after 5 weeks, are the combined result of both processes. By using indicators that are directly related to grass growth, the stimulating effect of slurry on herbage growth is intrinsically part of the evaluation of rejection. However, Prins & Van Burg (1979) concluded that in field experiments it takes at least 10 days before effects of different levels of N application can be observed, which implies that differences in change of herbage height after one week (CHH) were primarily caused by differences in grazing behaviour.

The animals had free access to the whole pasture, but only 2% of the area was treated with slurry. Indifference of the animals to graze on the slurry-treated plots would imply a decrease in CHH similar to that of the control plots. However, all slurry-treated plots showed a significantly higher mean CHH (Table 3.4) than the controls, indicating that all slurries indeed caused herbage rejection. Moreover, indifference also would imply a HOM yield on the slurry-treated plots more or less equal to the yield on the control plots. However, for the APMlac, OSK and MAR slurries this yield was significantly higher (Table 3.4), which is another indication that these slurries did cause rejection.

Several researchers observed herbage being rejected near faeces or slurry (Marten & Donker, 1964; Garstang & Mudd, 1971; Bosker *et al.*, 2002). Marten & Donker (1966) showed that non-acceptability of manure-affected pasture was not associated with characteristics of the pasture but directly with the manure itself. Dohi *et al.* (1991) demonstrated that odour is the major cause of herbage rejection. Odour is most closely related to concentrations of VFA and volatile aromatic compounds (Zahn *et al.*, 2001) for which carbohydrates and proteins are biochemical precursors (Mackie *et al.*, 1998). Miller & Varel (2001) - using a starch-rich diet - concluded that starch was the most likely biochemical source of fermentation products in cattle slurry. According to these authors protein fermentation will become dominant after starch has become limiting. In our study, CHH as an indicator of herbage rejection was significantly and positively correlated with the NH_3/NH_4^+-N content of the slurry. This may suggest that ammonia or other nitrogenous end products of protein fermentation were responsible for the herbage rejection.

3.4.2 Bio-assay

Possible inhibiting factors

A number of chemical substances in the slurry extracts were significantly and negatively correlated with the results of the cress germination test (Table 3.6), indicating that they all may play a role in the phytotoxic effects of the slurries. However, some of the substances also showed a strong mutual correlation. Fortunately, of a number of these substances, inhibiting mechanisms and critical inhibiting values for cress seeds are known.

NH_3/NH_4^+-N in solution can be toxic to plant growth. Its toxicity is mainly caused by ammonia (NH_3), which affects plant growth and metabolism even at (low) concentrations at which NH_4^+ is not harmful (Mengel & Kirkby, 1987). The concentration of ammonia depends on the concentration of NH_4^+-N via the equilibrium $NH_4^+(aq) \rightarrow NH_3\ (aq) + H^+$ and on the volatilization of NH_3 (Bennet & Adams, 1970). Several researchers have found that ammonia is playing an important inhibiting role in phytotoxicity experiments (Wong *et al.*, 1983; Tiquia & Tam, 1998). A NH_3 concentration of 0.13 mmol l^{-1} has been proven to be toxic, while a concentration proved of 6 $mmol^{-1}$ is lethal (Bennet & Adams, 1970). In our study the NH_3 concentrations (as calculated from pH and NH_4^+ concentration by means of the equilibrium equation) in the slurry extracts ranged from 0.02 to 4.30 mmol l^{-1} and were highly and significantly correlated with the results of the germination test at extract concentrations where inhibition occurred. Figure 3.2 shows that the germination index remained above 60 when NH_3 was below 0.13 mmol l^{-1} and that it dropped rapidly with higher concentrations. It therefore is very likely that ammonia played an important role in the phytotoxicity observed, especially in the range of 0.1–1.0 mmol l^{-1}. However, above 1 mmol l^{-1} no germination took place at all, although the lethal value of 6 mmol l^{-1} was not reached. This indicates that ammonia was not the only inhibiting factor in the slurry extracts.

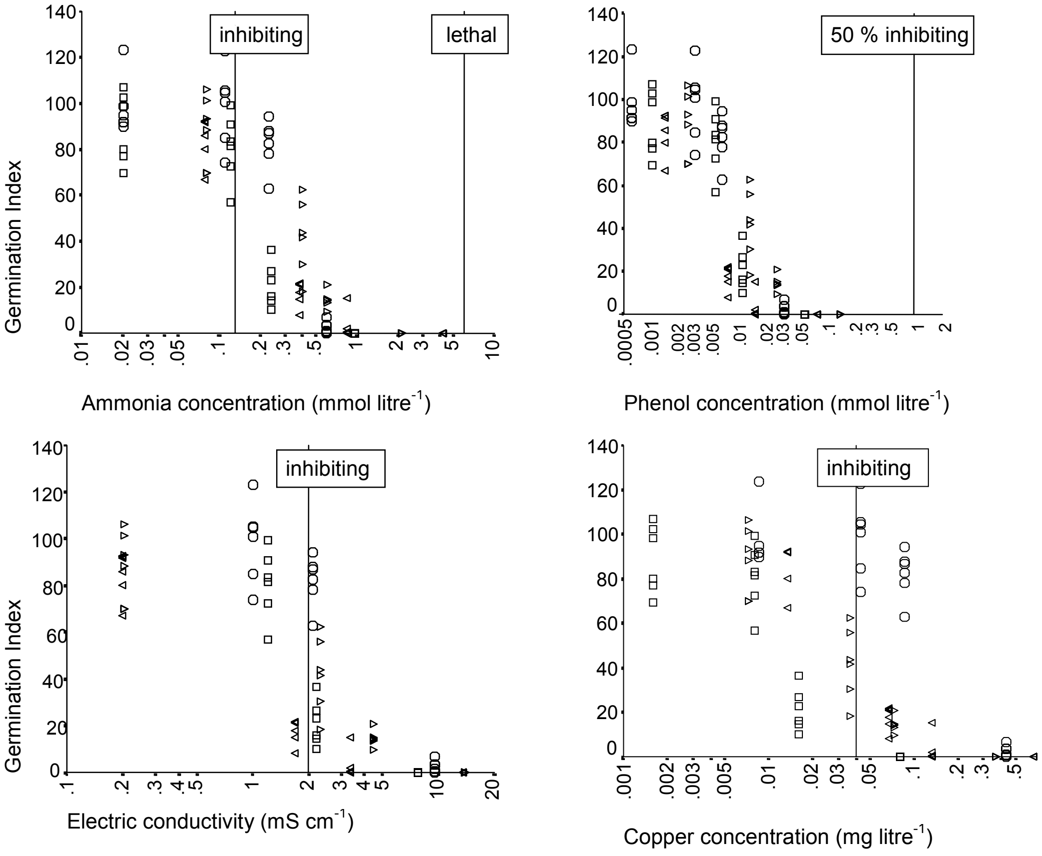

Figure 3.2 *Effect of different levels of ammonia, phenol and copper in, and electric conductivity of cattle slurry extracts on germination index of cress seeds. Vertical lines indicate inhibiting and lethal values from literature*

Also salinity can have a detrimental effect on seed germination and plant growth, especially in the seedling stage (Adriano *et al.*, 1973; Mengel & Kirkby, 1987). In general, salinity effects are mostly negligible in extracts with an EC of 2 mS cm^{-1} or less (Patrick *et al.*, 1963; Mengel & Kirkby, 1987). With extract concentrations of 0.5% and 1%, EC fluctuated around this critical value and was significantly correlated with RSG-24 and RRG. Figure 3.2 shows that the germination index indeed decreased rapidly around an EC of 2 mS cm^{-1}. These results indicate that apart from ammonia also salinity was an important inhibiting factor in our experiment.

Heavy metals can cause a marked delay in germination and can inhibit plant growth severely (Wollan *et al.*, 1978). However, critical concentrations at which heavy metals in slurry extracts become toxic are likely to be higher than the critical values found in literature, because of the relatively high amount of organic compounds that can bind heavy metals (Morel, 1983). Water-extractable Cd concentrations in this experiment ranged from 0.04 to 0.26 mg l^{-1}. The higher Cd concentrations may have had a slight inhibiting effect because they were similar to minimal inhibitory concentrations in substrates of 0.2 mg l^{-1} (Page *et al.*, 1972). However, no significant correlation of Cd concentrations with any of the results of the germination test was found. We therefore assume that Cd did not have an inhibiting effect.

Water-extractable Cu concentrations in the slurry extracts ranged from 0.004 to 0.68 mg l^{-1}, whereas 0.04 mg l^{-1} has been shown to inhibit root growth of plants (Craig, 1978). With the 0.5% and 1% extracts, Cu concentrations fluctuated around the critical value. The statistically significant correlation between Cu concentration and RSG-24 with the 1% extracts and RRG and GI with the 0.5% extracts, indicate that Cu concentration may have been an inhibiting factor. However, in a number of extracts with Cu concentrations below the critical range, low GI values were found, indicating that there were more inhibiting factors involved (Figure 3.2). On the other hand, some extracts with Cu concentrations far above the critical values showed a high GI, indicating that the inhibiting effect of Cu was not very strong. Concentrations of Zn in this experiment ranged from 0.015 to 1.43 mg l^{-1} and were below critical values found in literature, ranging from 75 mg l^{-1} to 600 mg l^{-1} (Davies, 1977; Webber, 1977). We therefore assume that Zn was not an inhibiting factor. The statistically significant correlation between Zn concentration and RSG-24 with the 1% extracts, and RRG with the 0.5% extracts can be explained by the strong correlation between Cu and Zn.

Negative effects of slurry may possibly be explained by the inhibitory effect of nitrogenous compounds like biogenic amines or phenolic compounds that result from the degradation of excessive protein (Van Bruchem *et al.*, 1999b). Indeed, phenol can have a negative effect on root growth. Arambasic *et al.* (1995) found a growth inhibition with cress of 50% at 0.86 mmol l^{-1}. However, even with the 5% extract, phenol never exceeded toxic limits: the highest value for phenol in the germination test was 0.075 mmol l^{-1} (Figure 3.2). The statistically highly significant correlation between phenol and the germination parameters can be explained by the high correlation between phenol and ammonia concentration ($R^2 = 0.99$). Also for indol and scatol high and statistically significant correlations with the results of the germination test were found, suggesting that indol and scatol may have had an inhibiting effect. However, these compounds were also strongly correlated with the concentrations of both NH_3/NH_4^+-N and total-N. Unfortunately, we did not find critical inhibiting values for these compounds in literature and cannot therefore draw any conclusion as to their direct inhibiting effect. The only biogenic amine detected was putrescine, in very low concentrations. Putrescine was significantly correlated with RSG-24 for the 1% extract and with GI for the 0.5% extract, so it may have inhibited germination and root growth. On the other hand, there was also a strong positive correlation of putrescine with the amount of Cu. So, again we cannot draw firm conclusions on the direct inhibiting effect of this amine, but considering its very low concentrations such an effect was not very likely.

Phytotoxicity and slurry quality

The bio-assay has made evident that slurry can be phytoxic to cress seeds and seedlings and that there were differences in this phytotoxicity between the four slurry types investigated. The ranking order of the slurries according to their phytotoxic effect (based on GI) was MAR > APMlac > OSK > APMdry for all extracts. The undiluted slurry extracts, except APMdry, permanently damaged all cress seeds, indicating that undiluted slurry is highly phytotoxic to cress seeds. The 1% extracts showed the largest differences in germination, whereas with the 0.5% extracts the largest differences were observed in root growth. These concentrations seem to be most appropriate to test phytotoxicity of slurry with cress seeds. Ammonia and EC appeared to be the most important slurry parameters with inhibiting effects. Besides, Cu may have had a weak inhibiting effect too. These findings are in agreement with the results of Groenwold & Keuning (1988), who observed in a pot experiment with perennial ryegrass that NH_4^+ and electric conductivity were the main factors causing toxicity. It is not clear whether other nitrogenous compounds also play a specific role in the inhibiting effect of slurry.

However, the ranking order of slurries based on their phytotoxicty to seeds and seedling roots was similar to the ranking order when based on herbage yield after five weeks of undisturbed growth. In other words, the slurry that showed greatest phytotoxicity in the seed germination bio-assay performed best in terms of herbage yield. A number of important factors could have played a role: (1) the buffering capacity of soil, (2) the sensitivity of the type of seed, (3) the difference between inhibition of seed germination and phytotoxicity to already existing roots and (4) differences in time scale of effects on germination and herbage growth. Therefore, we argue that it is necessary to use or develop other laboratory tests to evaluate slurry quality that show greater resemblance with what is observed in the field. In this respect the pot experiment with barley described by Kehres (1990) for testing compost quality can be an interesting alternative.

3.5 Conclusion

The dairy farmers of the environmental co-operatives VEL and VANLA are aiming at an improvement of slurry through an adapted feeding strategy (Verhoeven *et al*., 2003). In our study several characteristics of slurry quality that can be affected by feeding strategy were explored. The results show (1) short-term effects on N recovery and undisturbed herbage yield, (2) differences in herbage rejection by grazing heifers, and (3) differences in phytoxicity as observed in a cress seed bio-assay. However, the ranking order of slurries based on their phytotoxicty to seeds and seedling roots was similar to the ranking order when based on herbage yield after five weeks of undisturbed growth. In other words, the slurry that showed greatest phytotoxicity in the seed germination bio-assay performed best in terms of herbage yield. Therefore, we argue that it is necessary to use or develop other laboratory tests to evaluate slurry quality that show greater resemblance with what is observed in the field.

Chapter 4

Effects of different diets on utilization of N from cattle slurry applied to grassland on a sandy soil in the Netherlands

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Abstract

Dietary adjustments have been suggested as a means to reduce N losses from dairy systems. Differences in fertilizing value of dairy slurry as a result of dietary adjustments were evaluated in a one-year grassland experiment and by long-term modelling. Slurry composition of non-lactating dairy cows was manipulated by feeding diets with extreme high and low levels of dietary protein and energy. $C{:}N_{total}$ *ratio of the produced slurries ranged from 5.1 to 11.4. To evaluate their short-term fertilizer N value, the experimental slurries (n=8) and slurries from commercial farms with variable composition (n=4), were slit-injected in two grassland fields on the same sandy soil series in the north of the Netherlands (53°10′N, 6°04′E), with differences in sward age and ground water level. The recently established grassland field (NEW) was characterized by lower soil OM, N and moisture contents, less herbs and more modern grass varieties compared to the older grassland field (OLD). Slurry was applied in spring (100 kg N* ha^{-1}*) and after the first cut (80 kg N* ha^{-1}*) while in total four cuts were harvested. Artificial fertilizer N treatments were included in the experiment to calculate the Mineral Fertilizer Equivalent (MFE) of slurry N.*

The OLD field showed a higher total N uptake whereas DM yields were similar for the two fields. Average MFE of the slurries on the OLD field (47 %) was lower than on the NEW field (56 %), probably as a result of denitrification of slurry N during wet conditions in spring. Slurries from high crude protein diets showed a significantly higher MFE ($p<0.05$*) compared to low crude protein diets. No significant differences in MFE were observed between slurries from high and low energy diets. On both fields, MFE appeared to be positively related to the ammonium content (*$P<0.001$*) and negatively to the* $C{:}N_{total}$ *ratio of the slurry DM (*$P=0.001$*). Simulation of the effect of long-term annual application of 180 kg N* ha^{-1} *with highest and lowest* $C{:}N_{total}$ *ratio suggested that both slurries would lead to an increase in annual soil N mineralization. Both soil N mineralization and SOC appeared to be substantially higher in equilibrium state for the slurry with the highest* $C{:}N_{total}$ *ratio. It is concluded that in a situation with slit-injection, the reduced first-year N availability of slurry with a high* $C{:}N_{total}$ *ratio as observed in the grassland experiment will only be compensated for by soil N mineralization on the very long term.*

4.1 Introduction

Increasing the efficiency of N use in dairy cow feeding is an important tool for decreasing environmental pollution (Castillo *et al*., 2000; Børsting *et al*., 2003). Cattle slurry is a mixture of urine and faeces added with substances like bedding material and cleaning water. The N in slurry is particularly susceptible to volatilization and represents a major source for atmospheric pollution (Bussink and Oenema, 1998). This volatilization can be reduced by technical means such as adjustments of storage facilities and by using low-emission techniques, but also by a reduction of the protein content of dairy cow diets, resulting in lower total N contents in the slurry (Paul *et al*., 1998; Külling *et al*., 2001). In a number of pilot projects efficient protein feeding is applied as a means to increase farm N efficiency on commercial farms (Oenema *et al*., 2001; Chapter 2). Philips *et al*. (1999) reviewed different approaches for reducing ammonia emission from livestock buildings and identified dietary manipulation and generous use of bedding material to increase the C:N_{total} ratio of slurry as the most promising options.

At the same time, slurry is an important source of N for grassland production. After anaerobic slurry storage, slurry N is mainly found as ammonium N and organic N (Kirchmann and Witter 1992). Ammonium N is directly available to plants and it contributes to the fertilizer N value of slurry. A reduction of feed protein content reduces the proportion of N excreted with urine, resulting in a decrease of ammonium N in the slurry. Consequently, the fertilizer N value of slurry is negatively correlated with the dietary protein content (Paul *et al*., 1998; Sørensen *et al*., 2003).

Organic slurry N has to be mineralized before it is available for plant uptake. During microbial decomposition of organic compounds in applied slurry, part of the ammonium N will be immobilized in the soil (Sørensen and Jensen, 1995). The N mineralization/immobilization processes are influenced by the slurry composition and affect the fertilizing value of slurry. Janssen (1996) showed that for substances with equal decomposability, net mineralization linearly decreased with increasing C:N ratio of the organic material. Van Faassen and Van Dijk (1987) and Chadwick *et al*. (2000) reported a decrease of N mineralization from several types of organic manure, being related to the C:N_{org} ratio of the manure. Ruminant faecal N concentration has been shown to decrease with diet digestibility (Kyvsgaard *et al*., 2000; Sørensen *et al*., 2003). Therefore, diet digestibility is probably a determining factor for the C:N_{org} ratio of slurry. Kyvsgaard *et al*. (2000) showed indeed that the turnover of faecal N was influenced by the digestibility of the feed for sheep. In addition, Sørensen *et al*. (2003) showed a negative relationship between the Crude Fibre (CF) and Neutral Detergent Fibre (NDF) content and the fertilizer value of slurry.

Also long term effects of slurry can be affected by diet composition. Application of cattle slurry will result in considerable amounts of residual organic N which contribute to the accumulation of organic N in the soil (Sørensen and Amato 2002; Hao *et al*., 2003) and consequently to its fertilizer N value on the longer term (Maidl and Fischbeck, 1989; Paustian *et al*., 1992; Whalen *et al*., 2001). Its decomposition pattern in the soil throughout the years might thus be affected by diet composition. Schröder *et al*. (2005) concluded that omitting residual N effects might result in underestimation of the long term fertilizer N value, especially in manures that contain much organic N relative to ammonium N. However, in case the mineralization pattern is not synchronized with root activity, residual manure N may also increase N losses (Christensen, 2004).

Soil organic matter and organic N accumulation are determined by the input of C rather than the input of N (Ryden, 1984; Hassink, 1994). Soil organic carbon (SOC) increases with the amount of carbon added to the soil (Van den Pol-van Dasselaar and Lantinga, 1995). Recently established pastures will show a net accumulation whereas old pastures are expected to have (near) equilibrium values for both C and N (Whitehead, 1995). Higher risks for N leaching may thus be expected from old pastures under fixed applications of N compared to younger swards (Scholefield *et al*., 1993) whereas lower inputs of N in old pastures may result in equal outputs of N (Sonneveld and Bouma, 2003).

This paper investigates whether there are differences in fertilizer N value of slurries from non-lactating dairy cows, that have been fed diets with combinations of extremely high and low protein and energy levels, when applied to grassland. The fertilizer N value is related to chemical composition of both the diet and the slurry. A one-year experiment was conducted on two fields to test whether soils varying in organic N content (old and new grassland) react differently upon the different slurry types, both in terms of N yields and N losses. In addition, the effect of long-term application of cattle slurries varying in C:N_{total} ratio on the time course of soil organic C and N content and soil N mineralization was estimated using a simulation model.

4.2 Material & Methods

4.2.1 Slurry production

For the production of different types of slurry, a feeding experiment was carried out in a tie-stall from 21 January until 11 March 2003. The slurry pit was divided into eight compartments by means of wooden partitions. Above every compartment two non-pregnant, non-lactating Holstein Friesian cows were placed. No bedding material was used. Every pair of cows received one of the diets described in Table 4.1. The high and low protein levels in the diets were included to provide slurries with a large range of NH_4-N, as it has a large influence on the fertilizer N value of slurry. Diets with low energy contents were put together by using low digestible forages (LDGS and STR,

Table 4.1) to test whether these diets would result in immobilization of N as observed in a pilot field experiment (Chapter 3) and laboratory experiments (Kyvsgaard *et al.*, 2000). Concentrates were fed twice daily and forages were fed ad libitum just after the cows had finished the concentrates. Due to the limited slurry storage capacity the experiment was divided into two collection periods. Tables 4.1 and 4.2 show average data over the two collection periods. Samples of all feedstuffs were taken every three days and pooled per collection period. Refusals were collected and sampled every two days before the following morning feeding. Slurry collection started after a 3-week adaptation period on 11 February. Two weeks later, the slurry was intensively mixed and pumped into a 1000-litre polyethylene container. During pumping a sample of the slurry was taken. For the second collection period the procedure was repeated on 11 March. For some slurries water addition was necessary to be able to pump the slurry (Table 4.2). The containers were stored outdoors and transported to the experimental fields seven days later.

In addition, four slurries of variable composition from commercial farms were included in the field experiment (Table 4.2, no's 9–12), in order to compare the extreme experimental slurries with ‘regular’ dairy cattle slurries. These slurries were collected from local farms just before the first application date. To obtain variation in commercial slurry composition, the slurries were selected on farms varying in milk production level (6500–9000 kg cow^{-1} yr^{-1}), roughage type (grass silage with or without maize silage), estimated dietary crude protein (CP) level (140–170 g kg DM^{-1}) and bedding material (straw or sawdust).

Table 4.1 *Average (data from 2 collection periods) diet composition, dietary characteristics and calculated OM digestibility of the eight diets fed*

No.	Code	Type	Dietary components [a]	C:N Ratio	Intake (kg DM cow^{-1} day^{-1})	*Dietary characteristics (kg^{-1} DM)* NEL [b] (kJ)	CP (g)	OM (g)	NDF (g)	ADF (g)	Dig. OM (%)
1	GMH	Forages	60 % MS & 40 % HDGS	23.0	12.2	6700	182	930	376	238	72.1
		Concentrates	90 % SO & 10 % MA		3.6						
2	GYH	Forages	100 % HDGS	14.5	12.4	6679	200	905	405	247	79.9
		Concentrates	60 % SO & 40 % MA		3.3						
3	GOH	Forages	100 % LDGS	26.3	7.1	5513	185	878	487	327	68.0
		Concentrates	100 % SO		2.7						
4	SH	Forages	100 % STR	55.1	4.7	5327	187	945	502	336	61.3
		Concentrates	75 % SO & 25 % MA		4.1						
5	GML	Forages	60 % MS & 40 % HDGS	23.0	9.9	6693	115	931	397	240	72.5
		Concentrates	55 % MA & 45 % BP		3.0						
6	ML	Forages	100 % MS	38.0	11.9	6700	101	953	371	233	73.6
		Concentrates	43 % SO & 21 % MA & 36 % BP		2.4						
7	GOL	Forages	100 % LDGS	26.3	6.9	5327	110	869	549	353	64.0
		Concentrates	19 % SO & 81 % BP		2.5						
8	SL	Forages	100 % STR	55.1	4.0	5251	105	932	559	353	64.0
		Concentrates	21 % SO & 21 % MA & 58 % BP		4.1						

a) MS= Maize Silage; HDGS= High Digestible Grass Silage; LDGS= Low Digestible Grass Silage; STR= Straw; SO= Soya; MA= Maize; BP= Beet Pulp

b) According to Dutch standards for net energy lactation (Anon., 2005a)

Table 4.2 *Chemical composition of slurries used in the field experiment*

				Slurry composition (g kg^{-1} DM)					
Slurry	Diet	Water added[a] (%)	DM (g kg^{-1})	OM	Total C	Total N	NH_4-N	C:N$_{total}$ ratio	C:N$_{org}$ ratio
Experimental slurries[b]									
1	GMH	0	104	786	417	70	48	5.9	19.1
2	GYH	0	102	700	397	78	45	5.1	12.4
3	GOH	0	131	698	382	59	38	6.4	17.8
4	SH	11	93	849	446	66	48	6.8	25.2
5	GML	9	113	775	417	50	27	8.4	18.7
6	ML	8	111	843	445	46	28	9.6	23.8
7	GOL	10	125	710	380	33	17	11.4	22.9
8	SL	19	101	813	429	42	26	10.1	27.0
Average experimental			*110*	*772*	*414*	*56*	*35*	*8.0*	*20.9*
Commercial slurries[c]									
9	COM1		117	658	385	34	13	11.2	18.6
10	COM2		84	756	422	46	24	9.1	18.6
11	COM3		108	753	417	46	21	9.1	16.7
12	COM4		82	763	424	59	34	7.2	17.1
Average commercial			*98*	*733*	*412*	*46*	*23*	*9.2*	*17.8*
Average total			*106*	*759*	*413*	*52*	*31*	*8.4*	*19.8*
Reference[d]			*86*	*744*	*409*[e]	*51*	*26*	*8.0*	*16.0*

c) To some of the slurries water had to be added to be able to pump the slurry. Percentage is based on fresh weight during collection.

d) Slurry (n=8) obtained from an experiment with non-lactating dairy cows fed different diets. Diets are described in Table 4.1

e) Slurry (n=4) obtained from commercial farms in the Netherlands with different nutrition management.

f) Average dairy cattle slurry composition in the Netherlands (De Visser et al., 2005)

*g) Assuming a C content of 0.55 * OM, being the mean value of the twelve slurries in the experiment.*

4.2.2 Experimental fields

A one-year experiment was performed at two pasture fields located on the same sandy soil series in the north of the Netherlands (53°10′ N, 6°04′ E). The soils are classified as Gleyic Podzols with an anthropogenic topsoil down to between 30 and 50 cm depth. The groundwater table at both fields generally fluctuates between 25 cm and 80 cm beneath the surface in wintertime but may drop below 120 cm beneath the surface in summertime. At the time of the experiment, one sward (NEW) had been used as grassland for 5 years after a previous history of 12 years silage maize cultivation. The other sward (OLD) was at least 38 years under permanent unploughed grassland. Both swards have experienced a mixed mowing and grazing regime with a long history of annual slurry application. The soil is typical for this area with an anthropogenic topsoil of 30–50 cm and the presence of glacial till in the subsoil. Soil properties for both fields, which are about 2 km apart from each other, are described in more detail in Table 4.3.

Table 4.3 *Soil properties of the fields [a] used in the experiment*

	NEW [b]			*OLD* [c]		
	0–25 [d]	25–50 [d]	50–75 [d]	0–25 [d]	25–50 [d]	50–75 [d]
OM (g 100 g^{-1} soil)	3.5	3.4	1.6	6.0	4.8	2.1
N organic (g 100 g^{-1} soil)	0.155	0.130	0.058	0.284	0.171	0.068
Total C/N	12.1	14.6	15.9	11.6	16.1	17.2
Texture (% particles <2μm)	5.0	4.3	3.2	5.9	5.5	3.1
Texture (% particles <50 μm)	26.3	24.2	22.1	30.4	36.3	21.1
Bulk density (g cm^{-3})	1.51	1.53	1.49	1.28	1.41	1.49

a) Both fields were located on the same sandy soil series (Gleyic Podzols) in the north of the Netherlands. Ground water levels during the experiment are described in Figure 4.1.

b) The NEW field had been used as grassland for 5 years after a previous history of 12 years silage maize cultivation

c) The OLD field was at least 38 years under permanent unploughed grassland

d) Depth (cm)

Apart from higher levels of organic matter and organic N, OLD was also characterized by a lower bulk density and hence a higher porosity. The botanical composition, visually estimated by an experienced investigator for the individual plots, was different between the two fields with a dominance of *Lolium perenne* in the NEW sward (66%) and a combination of various grass (87%) and herb species (13%) in the OLD sward (Table 4.4).

Prior to the start of the field experiment, in both fields a piezometer was installed at a depth of 200 cm. A weather station (Watchdog®, Spectrum Technologies, Inc) was installed at the location of the NEW field. Air temperatures recorded by the station ranged from –4,1 °C (early April) to 34,5 °C (early August). Monthly precipitation and bi-weekly recordings of groundwater levels for the period April–December are given in Figure 4.1. Higher groundwater levels for field OLD were due to the presence of glacial till closer to the surface (70 cm depth) compared with field NEW (200 cm depth).

Table 4.4 *Average botanical composition [a] of the plots on both experimental fields[b]*

		NEW	OLD
Grass Species		*97*	*87*
- Perennial ryegrass	(*Lolium Perenne*)	66	34
- Rough meadow grass	(*Poa Trivialis*)	25	31
- Annual meadow grass	(*Poa Annua*)	5	6
- Couch grass	(*Agropyron repens*)		8
- Creeping bent grass	(*Agrostis stolonifera*)		5
- Other grasses		1	3
Smooth meadow grass	(*Poa pratensis*)		
Timothy	(*Phleum pratense*)		
Marsh foxtail	(*Alopecurus geniculatus*)		
Herb species		*3*	*13*
- Dandelion	(*Taraxacum officinale*)		5
- Chickweed	(*Stellaria media*)	2	3
- Creeping buttercup	(*Ranunculus repens*)		2
- Cuckooflower	(*Cardamine pratensis*)		2
- Other herbs		1	1
Shepherd's purse	(*Capsella bursapastoris*)		
Broad-leaved Dock	(*Rumex obtusifolius*)		
Common Sorrel	(*Rumex acetosa*)		
Common Meadow buttercup	(*Ranunculus acris*)		
Lesser Celandine	(*Ranunculus ficaria*)		

a) In % of dry weight. Data obtained before the first cut

b) Properties of the fields are described in Table 4.3

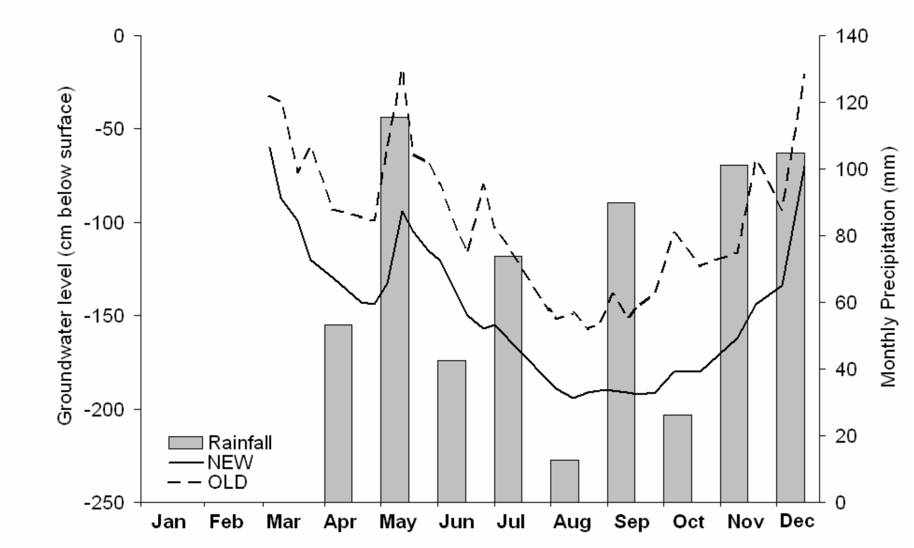

Figure 4.1 *Groundwater level fluctuation on two fields (NEW and OLD) and monthly precipitation*

4.2.3 Field experiment

The slurry of the first experimental period was applied during two days (25 and 26 March) on small plots (3.2 * 10 m) on both fields. The slurry of the second period was applied a few days after the first cut (27 and 28 May), after outside storage in the containers. Application was made with a Vredo® slit injection unit. For every treatment, there were three replicates per field, organized in three blocks and randomised. The application rate was calculated from the difference in weight of the unit before and after application on the 6 plots. Target application rates were the equivalent of 100 kg N ha^{-1} for the first cut and 80 kg N ha^{-1} for the second cut. However, due to differences in dry matter content, particle size and consistency of the slurries and the lack of enough slurry to calibrate the correct application speed, real application rates differed from these targets, especially for the second cut (Table 4.5). Separate treatments with four levels of artificial fertilizer N (calcium ammonium nitrate) were added to the experiment of which 55% was applied before the first cut at the start of the growing season and 45% before the second cut, i.e. 45 kg N (25 + 20), 90 kg N (50 + 40), 180 kg N (100 + 80) and 250 kg N (140 + 110), all with three replicates. To obtain a reliable estimate for the N uptake on the unfertilized plots, there were 6 control plots without N fertilization per field. All treatments received ample additional phosphorus and potassium through inorganic fertilizers. After the second cut no further fertiliser applications were made. The plots were harvested at 4 times during the growing season (21 May, 2 July, 14 August and 20 October) using a Haldrup® forage harvester. Third and fourth cuts were harvested to evaluate the residual effects of slurry application on DM yield and N uptake. The cut area was 10 m * 1.5 m and 5–6 cm stubble was left. Fresh weight yields were recorded and representative herbage samples were taken for analysis.

As total N uptake responded linearly to an increase of mineral fertilizer N on both fields, MFE of slurry N was calculated according to:

$$MFE\ (\%) = Equivalent\ Fertilizer\ N\ Response\ (EFR) / Total\ Slurry\ N * 100\% \qquad (4.1)$$

where EFR is the amount of N (kg ha^{-1}) needed from mineral fertilizer to attain the same N yield as observed in the slurry-treated plot, according to the linear fertilizer N response equations.

Ammonia emission (Table 4.5) was modelled using the ALFAM model described by Søgaard *et al.* (2002), using average air temperature and wind speed on application date, slurry type (dairy cattle), DM and ammonium content of the slurries, application technique (open slot), application rates and measuring technique (Micrometeorological Mass Balance) as inputs. For some of the slurries the DM or ammonium content of the slurries was just out of the range of the experimental data behind the model. The measured MFE was corrected for ammonia emission (kg N ha^{-1}), giving a potential MFE under conditions without ammonia volatilization: $MFE_{corrected}$, according to:

$$MFEcorrected\ (\%) = (EFR + Am.Em.) / Total\ Slurry\ N * 100\% \qquad (4.2)$$

MFE of organic N ($MFE_{organic}$) was calculated based on the assumption that ammonium N which does not volatilize is 100% available, according to:

$$MFEorganic\ (\%) = (EFR - (Slurry\ NH4\text{-}N - Am.Em.)) / Organic\ Slurry\ N * 100\% \qquad (4.3)$$

Table 4.5 *Amounts of slurry applied during the experiment and modelled ammonia emission*

Slurry[a]	*Slurry application*				*Modeled ammonia emission* [b]		
	March[c] (Mg ha^{-1})	May[d] (Mg ha^{-1})	Total[e] kg C ha^{-1}	Total*** kg N ha^{-1}	% of Applied NH4-N	% of applied N	Total Loss kg N ha^{-1}
GMH	13.5	8.7	925	162	14.5	9.9	16.1
GYH	12.6	7.4	795	157	15.5	8.9	14
GOH	12.7	6.5	737	151	19.3	12.4	18.8
SH	17.2	13.9	1385	189	14.2	10.3	19.5
GML	28.1	9.9	1579	213	22.5	12.2	25.9
ML	18.3	23.5	1859	215	21.2	12.9	27.8
GOL	21.8	25.9	1811	199	30.0	15.5	30.8
SL	19.9	16.4	1557	155	21.5	13.3	20.6
COM1	34.1	20.6	2109	219	26.2	10.0	21.9
COM2	22.8	22.0	1889	173	19.8	10.3	17.9
COM3	20.9	23.9	1869	222	24.5	11.2	24.8
COM4	21.3	23.0	1877	213	17.0	9.8	20.9

a) Slurry composition is described in Table 4.2
b) Ammonia emission modelled according to Søgaard et al. (2002)
c) Before the start of the growing season (25 and 26 March)
d) After the first cut (27 and 28 May)
e) Total of the two applications

4.2.4 Analytical methods

All feed, slurry and grass samples were analyzed for dry matter content, after drying at 103 °C and for ash, by combustion in a furnace at 550 °C. Feed samples were analyzed for total N, using the CE Instruments EA 1110® CHN analyser after freeze-drying. CP in the feed was calculated as total N * 6.25. NDF and ADF in the feed were analyzed after freeze-drying according to Van Soest *et al.* (1991). Total N in fresh slurry samples and dried grass samples was analyzed with the Kjeldahl method (ISO 5983). Total C of the slurry samples was determined after freeze-drying by elemental analysis using an EA 1110 CHN analyser (CE instruments, Milan, Italy). NH_3/NH_4^+-N in the slurry was determined according to the Berthelot method (Anon., 1974)

Soil samples were collected 4 times during the growing season with 2-monthly intervals (April 14th, June 4th, August 11th, October 14th). These were taken from all replicates of the control plots, three artificial fertilizer plots and the slurry plots GYH and GOL at depths of 0–25, 25–50 and 50–75 cm. Per replicate, three samples were taken from each depth, bulked and, after 1 M KCL extraction, analyzed for soil inorganic N (NO_3 and NH_4) using the Fison instruments EA 1108 CHN® analyser. Gravimetric water content was also determined (105 °C).

All statistical analyses were done using SPSS (Anon., 2001). Relations between dietary (Table 4.1) and slurry characteristics (Table 4.2) were tested using stepwise regression. Differences in MFE were initially tested using an analysis of variance (GLM) with slurry and field as factors and botanical composition as a co-variable. No significant interaction between field and slurry was detected and therefore botanical composition was not included in the final model. Differences in MFE between groups of slurries were tested afterwards with a T-test. Relations between slurry characteristics and average MFE were tested using a GLM with field as factor and slurry characteristics as a covariate for the combined data of both fields. Significant interactions between field and slurry characteristics were not revealed.

4.2.5 Simulation of long-term effects

Long-term effects of application of different slurry compositions on the time course of soil N and C content of the top 25 cm and subsequent mineralization were simulated for the experimental slurries with highest and lowest $C{:}N_{total}$ ratio (slurry no. 2 and 7, Table 4.2) for both fields (OLD and NEW) using the following equation, based on Groot *et al.* (2003):

$$NMIN_{component} = \left(\frac{k_{component}}{1-eff}\right) \times C_{component} \times \left(\frac{eff}{q_B} - \frac{Norg_{component}}{C_{component}}\right) \qquad (4.4)$$

In this equation $NMIN_{component}$ is the annual mineralization of N (kg ha^{-1}) from the components soil, slurry and unharvested biomass (UBM) respectively, $k_{component}$ is the annual decomposition rate of organic matter from slurry (k_{slurry}), soil (k_{soil}) and unharvested biomass (k_{UBM}) in %, *eff* is the efficiency of biomass conversion by soil biota and q_B is the C/N ratio of soil biota. The change in soil N and C and the subsequent *available Ninorg* were calculated according to:

$$\partial Norg_{soil} = Norg_{slurry} - NMIN_{slurry} - NMIN_{soil} + Norg_{UBM} - NMIN_{UBM} \qquad (4.5)$$

$$\partial C_{soil} = (1 - \mathrm{k}_{\mathrm{slurry}}) \times C_{slurry} + (1 - k_{UBM}) \times C_{UBM} - k_{soil} \times C_{soil} \qquad (4.6)$$

$$availableNinorg = (1 - \alpha) \times Ninorg_{slurry} + NMIN_{soil} + \mathrm{NMIN}_{\mathrm{slurry}} + NMIN_{UBM} \; (4.7)$$

In these equations *C*, *Ninorg* and *Norg* represent the amounts of carbon, inorganic N and organic N (kg ha^{-1}) for the different components, α represents the % of inorganic N lost by ammonia emission after application. *Available Ninorg* denotes the amount of inorganic N (kg ha^{-1}) that is available from slurry, slurry mineralization and soil mineralization for grass uptake on a yearly basis. Parameter estimates were taken from Groot *et al*. (2003), unless indicated otherwise. Model calculations were performed assuming an annual inorganic N withdrawal of grass of 95%, indicating that 5% of the mineralized N was not used for either uptake or emission. Annual decomposition of unharvested biomass (k_{UBM}) was estimated at 70% and annual soil C decomposition (k_{soil}) was estimated at 1.6%, following observations of Kortleven (1963). Decomposition of organic matter in slurry (k_{slurry}) was assumed to be linearly related to the organic matter digestibility of the diet (0.5 * diet OM digestibility), resulting in ranges of the humification coefficient ($1\text{-}k_{slurry}$) similar to those observed by Janssen (1996). The value of q_B was set at 8.0, *eff* was assumed to be 30% and α equaled 20%. Annual unharvested biomass was fixed at 6500 kg DM ha^{-1}, implying C and N inputs of 2630 and 65 kg ha^{-1} yr^{-1}, respectively. For the initial values of the soil pools data from Table 4.3 (0–25 cm) were used. Slurry input was fixed at 180 kg N ha^{-1} and slurry characteristics were taken from Table 4.2.

4.3 Results and Discussion

4.3.1 Slurry composition

Non-lactating dairy cows have very low requirements for energy and protein due to the absence of milk production. The low energy requirement made it possible to use forages with a very low digestibility (STR and LDGS) in the experiment. The low protein requirements implied a higher excretion of N in faeces and urine compared to lactating cows with the same protein intake. Furthermore, it should be noted that only two cows per diet were used. This implies that differences between diets are heavily affected by feed intake, water intake and digestion efficiency of the individual animals. Therefore, the relations between diet and slurry characteristics observed in this experiment cannot be directly extrapolated to any other situation, especially not for lactating cows.

Even after addition of water to some of the slurries, DM contents of the experimental slurries were high compared to a Dutch reference value (De Visser *et al.*, 2005, Table 4.2). It is not likely that these high DM contents were caused by the use of non-lactating cows as data obtained by Holter and Urban (1992) show that the average water content of the combination of urine and faeces is similar for dry cows in comparison with lactating cows. Besides the absence of cleaning water, the high DM content of the experimental slurries could have been caused by the specific diet composition or the short storage time in this experiment since the DM content of the slurries decreased during storage (data not shown) as also observed by Sørensen (1998).

The experimental slurries showed a large range in total N content (33–78 g kg^{-1} DM) and $C:N_{total}$ ratio (5.1–11.4). In this experiment, the largest part of the variation in $C:N_{total}$ ratio could be explained by a combination of the CP (84%) and NDF (12%) content of the diet ($P=0.001$). Total N contents of the experimental slurries were on average higher than the commercial slurries, which showed a range around the Dutch reference value of 51 g kg^{-1} DM (Table 4.2). Organic N in slurry is mainly derived from faecal N and earlier studies have shown that the concentration of N in faeces from ruminants is related to the digestibility of the diet (Kyvsgaard *et al.*, 2000; Sørensen *et al.*, 2003). To obtain slurries with a wide range in $C:N_{org}$ ratio, diets with a large range in digestibility were included in the experiment. The experimental slurries indeed showed a large variation in $C:N_{org}$ ratio (between 12.4 and 27.0) compared to the commercial slurries (between 16.7 and 18.6) which were all slightly higher than the reference value of 16.0. The largest part of the variation (78%) in $C:N_{org}$ ratio for the experimental slurries could be explained by the C:N ratio of the forage part of the diet ($P=0.004$).

4.3.2 Modelled ammonia emission

With field application of cattle slurry, the concentration of total ammoniacal N, pH and slurry DM are considered to be the main manure characteristics that determine ammonia volatilization (Jarvis & Pain, 1990). In this experiment slurries were used with a wide range in ammonium contents (Table 4.2). Modelled losses of N averaged over both application dates, varied between 14.5 and 30% of NH_4-N applied (Table 4.5), with an average of 20.5%. This average is close to the average loss for slit injection of 17% of applied NH_4-N reported by Huijsmans *et al.* (2001) based on an analysis of a large dataset.

Several authors have shown that reductions in dietary protein significantly reduce N emissions from cow houses (Paul *et al.*, 1998; Külling *et al.*, 2001; Misselbrook *et al.*, 2005a). From an environmental point of view it would be very interesting if a reduction of the ammonium content would also result in a decreased N volatilization from field application. However, as a result of a negative correlation between the DM content and the NH4-N content for both the experimental (R^2=0.70, without water addition) as well as the commercial slurries (R^2=0.77), no positive correlation between slurry NH_4-N content and total N losses was observed. On the contrary, the slurry with the lowest NH_4-N content showed highest modelled N losses (Table 4.2, slurry no. 7) due to its high DM content. The DM content of slurry is known to have a strong effect on ammonia emission as a result of reduced infiltration (Sommer *et al.*, 2003). Though the observed relation between slurry DM and NH_4-N content of the experimental slurries might be biased by individual water intake of the cows, this relation has been observed before (Holter and Urban,1992; Smits *et al.*, 1995; Misselbrook *et al.*, 2005a). It can be explained by a higher water intake and urine volume with high protein diets (Holter and Urban, 1992). Therefore, this observation clearly highlights a limitation to the potential to reduce ammonia losses from field application of undiluted slurry by means of a reduction of the dietary protein content.

Misselbrook *et al.* (2005b) conclude that slurry DM is the most important manure factor in N volatilization from cattle slurry applied to grassland but also slurry pH might affect N volatilization. However, in the model we used (Søgaard *et al.*, 2002), slurry pH is not included and also in the empirical model of Misselbrook *et al.* (2005b) slurry pH is not a decisive factor in the total N lost from slurry application to grassland. It's known that also slurry pH can be affected by diet composition. In an experiment with dairy cows Misselbrook *et al.* (2005a) showed that a reduction in protein content coincided with a reduction in pH. This was also shown for fattening pigs (Misselbrook *et al.*, 1998, Portejoie *et al.*, 2004). For our slurries, pH was not measured prior to application, but pH in the fresh slurries ranged from 7.2 to 8.4 and was also significantly higher for the high protein diets (Van der Stelt, personal communication). The relation between slurry ammonium, pH and DM content needs further investigation to evaluate the potential of reduction of ammonia volatilization from field application by means of a reduction in the dietary protein content.

4.3.3 Relation between N application, N uptake and DM yield in the field experiment

Figures 4.2 and 4.3 show the relation between N application, N uptake and DM yield for the different cuts in this experiment. In Figure 4.3A, data of the third and fourth cut were pooled. These data are denominated as later cut yields. Due to the low summer precipitation, later cut yields were low. In Figure 4.3B total yields from the four cuts are presented.

In the first and second cut, the OLD field showed a higher N uptake compared to the NEW field ($P<0.01$, Figures 4.2A and 4.2B, quadrant IV). N uptake responded linearly to N application with artificial fertilizer on both fields, except for the second cut on the OLD field. Total N uptake of the fertilized plots was linearly related to N application with artificial fertilizer for both fields ($R^2=0.99$, $P<0.001$, Figure 4.3B, quadrant IV). The slope of the fertilizer response curve was equal for both fields (0.71). Total N uptake was consistently higher in the OLD field ($P=0.01$). Total N uptake of the unfertilized plots was significantly lower on the NEW field (105 kg N ha^{-1}) compared to the OLD field (147 kg N ha^{-1}) ($P<0.01$), suggesting a higher net soil N mineralization on the OLD field. This higher value was expected from the higher organic N content, but also differences in rooting structure and density, botanical composition and historical manure application could have had an important effect on this difference in net mineralization.

At the first cut (Figure 4.2A, quadrant I) the DM yield per kg N uptake was much higher in the NEW field ($P<0.001$), resulting in a far higher DM yield (Figure 4.2A, quadrant II). This difference could have been related to differences in botanical composition as well as initial ground water levels**.** The presence of modern varieties of high productive grasses probably implied a higher growth rate for the NEW field compared to the OLD field as grassland types from old pastures are generally characterized by a very late heading date, a prostrate growth habit and a slow spring growth (Lackamp, 1977). The higher groundwater level at the OLD field could have decreased soil aeration and soil temperature which inhibits initial grass growth. At the second and following cuts (Figure 4.2B and 4.3A, quadrant I) this difference in DM yield per kg N uptake had disappeared. Differences in DM yield per kg N uptake between artificial fertilizer and slurry emerged only at the second cut on the NEW field (Figure 4.2B, quadrant I). This might be explained by a better distribution of N from fertilizer compared to slit injection in this period with low precipitation, as described by Van der Meer *et al*. (1987).

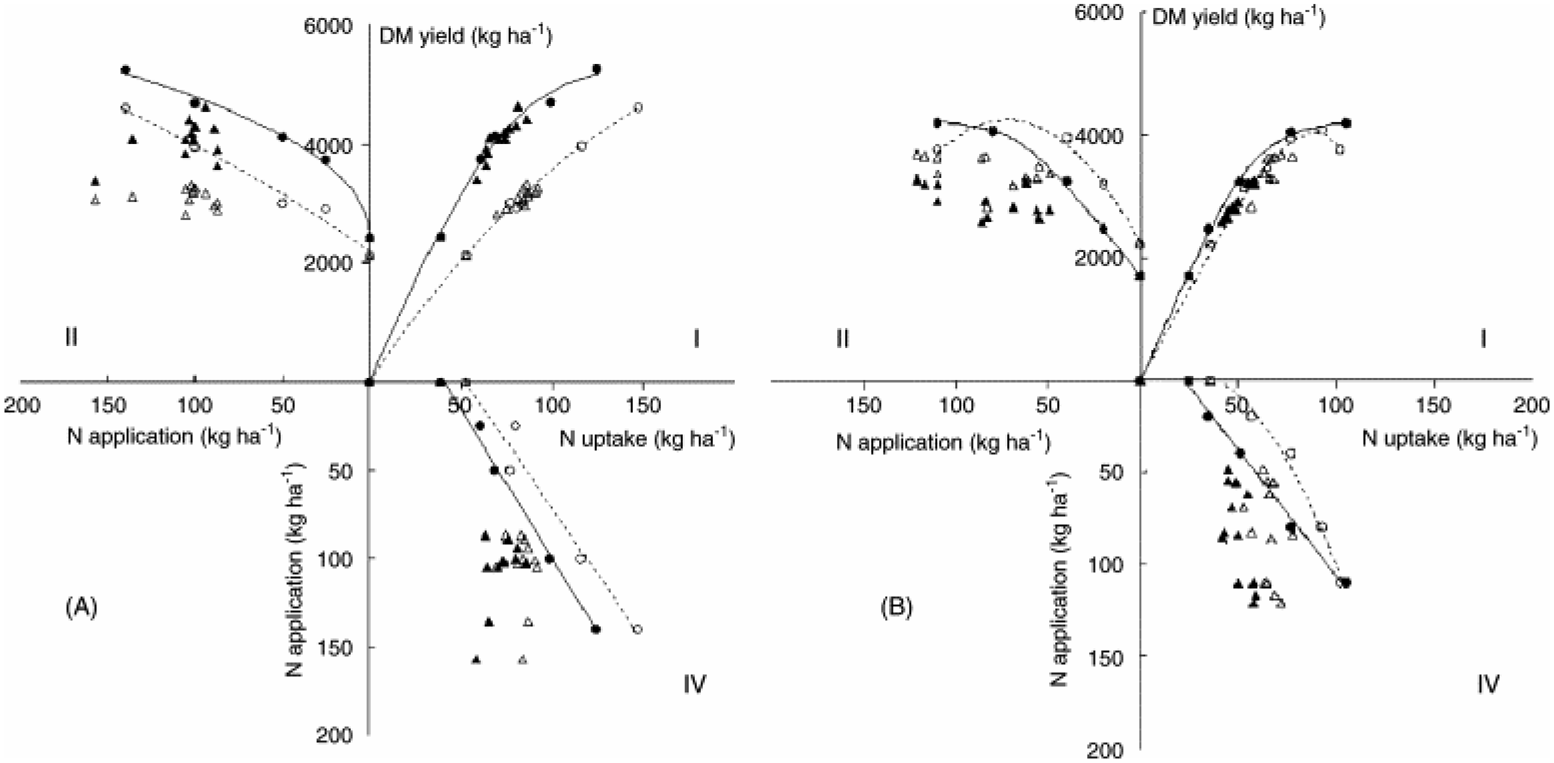

Figure 4.2 *Relationship between N application, N uptake and DM yield on a NEW and OLD field for artificial fertilizer ((●) NEW and (○) OLD) and slit-injected cattle slurry ((▲) NEW and (Δ) OLD) for the first (A) and second cut (B). Regression lines are fitted for artificial fertilizer data*

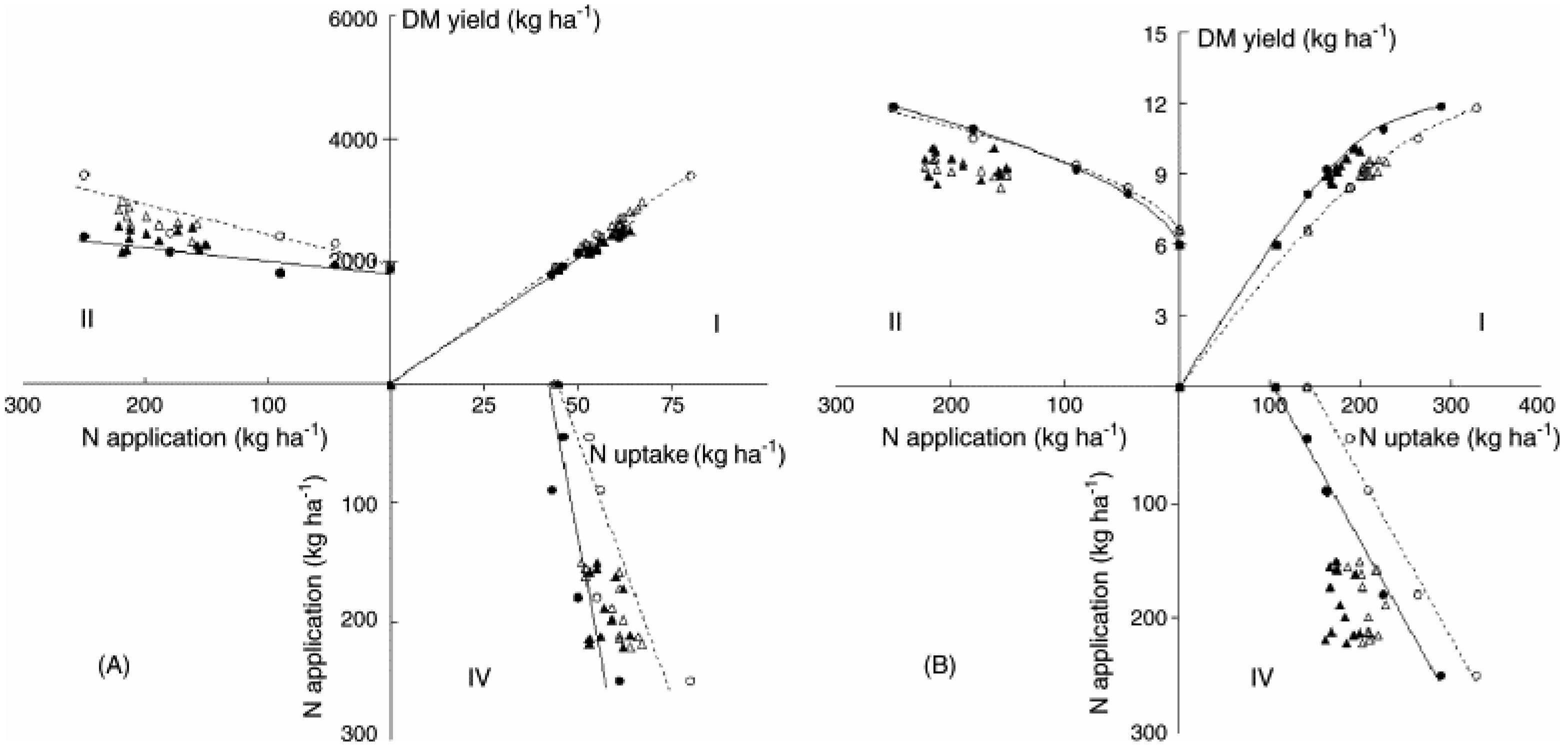

Figure 4.3 *Relationship between N application, N uptake and DM yield on a NEW and OLD field for artificial fertilizer ((●) NEW and (○) OLD) and slit-injected cattle slurry ((▲) NEW and (Δ) OLD) for later cuts (A) and total experiment (B). Regression lines are fitted for artificial fertilizer data*

Unlike the first cut (Figure 4.2A, quadrant II), DM yields were higher for the OLD field in second and later cuts ($P<0.001$, Figure 4.2B and 4.3A, quadrant II). Here, the higher N uptakes were reflected in higher DM yields. The DM yield of the later cuts increased with fertilizer application rate ($P<0.01$), especially on the OLD field ($P<0.001$, Figure 4.3A, quadrant II). At all fertilizer application rates, total DM yield was equal for both fields, whereas the unfertilized plots showed a slightly higher ($P<0.10$) DM yield on the OLD field (Figure 4.3B, quadrant II). Also for the slurry-treated plots there was no difference in total DM yield between the fields.

At the first cut, DM yield of the slurry-treated plots showed a large variation on the NEW field (Figure 4.2A, quadrant II). On the NEW field, the slurry with the highest application rate (GML) showed lowest yield, indicating an inhibiting effect of the slurry on grass growth. However, it is not clear whether this effect was caused by the large application rate or by the chemical or physical characteristics of this specific slurry. On both fields, slurry application increased later cut yields slightly compared to the control plots ($P<0.05$, Figure 4.3A, quadrant II). On the OLD field, the yield of the later cuts was significantly related to the total N application rate with slurry ($P<0.001$).

4.3.4 Soil sampling

Soil moisture was always higher in the OLD grassland compared to the NEW grassland. For both fields, the lowest volumetric water contents were recorded in August for all plots. These were on average 13 and 22% for the NEW and the OLD field, respectively. Soil water availability, calculated as the amount of water between field capacity (pF 2.0) and wilting point (pF 4.2), using the relationships of Wösten (1997) was more than 10 mm higher for the OLD grassland compared to the NEW grassland. Hence, reduced N uptake as a consequence of water stress could have been expected at an earlier stage in the NEW field. This might explain the higher response for the OLD field in later cuts to N application than in previous cuts (Figure 4.3A II).

Average soil inorganic N contents for the 0–75 cm soil profile in autumn, corrected for bulk density, are given in Table 4.6. The NEW field showed higher inorganic N values for nearly all treatments, on average about 10 kg ha^{-1} above those of the OLD field. These differences were never significant. Plots that had received slurry or fertilizer did not show increased inorganic N values compared to the unfertilized plots. When these slurry fertilization strategies will be applied on the long term, it is not likely that the nitrate standard for the groundwater will be exceeded as inorganic N contents did not approximate the levels reported by Hack-ten Broeke *et al.* (2004) that will result in nitrate concentrations exceeding the standard EU threshold.

Table 4.6 *Average soil mineral N levels in autumn [a] for different spring fertilization types on two fields [b]*

Fertilization			*Soil mineral N (0–75 cm soil, kg N ha^{-1})*	
Type	Application rate (kg N ha^{-1})	No. of plots	NEW [b]	OLD [b]
No	0	6	51	24
CAN [c]	90	3	43	23
CAN [c]	180	3	36	33
CAN [c]	250	3	27	28
Slurry GYH [d]	157	3	33	44
Slurry GOL [d]	199	3	41	33

a) *Measured at the end of the growing season (14 Oct)*
b) *Soil properties of the fields are described in Table 4.3*
c) *CAN = Calcium Ammonium Nitrate*
d) *Slurry composition described in Table 4.2*

Table 4.7 *Mineral fertilizer equivalent (MFE) of 12 different slurries applied on two grassland fields [a]*

	Diet type [a]		*MFE (% of total N)* [c]		
Slurry [a]	Forage [b]	Protein	NEW (n=3)	OLD (n=3)	Mean
GMH	60% MS & 40% HDGS	High	78 (7)	48 (7)	63 (8)
GYH	100% HDGS	High	63 (17)	65 (4)	64 (8)
GOH	100% LDGS	High	64 (7)	50 (13)	57 (7)
SH	100% STR	High	54 (7)	62 (10)	58 (6)
GML	60% MS & 40% HDGS	Low	42 (2)	42 (4)	42 (2)
ML	100% MS	Low	57 (5)	48 (6)	53 (4)
GOL	100% LDGS	Low	56 (3)	45 (14)	51 (7)
SL	100% STR	Low	56 (5)	36 (2)	46 (5)
COM1	Commercial slurry		37 (7)	41 (6)	39 (4)
COM2	Commercial slurry		51 (9)	46 (16)	48 (8)
COM3	Commercial slurry		51 (7)	36 (9)	43 (6)
COM4	Commercial slurry		62 (5)	43 (8)	52 (6)
	Mean		56 (3)	47 (3)	51 (2)

a) *Diets, slurry and field characteristics are described in Table 4.1–4.4.*
b) *MS= Maize Silage; HDGS= High Digestible Grass Silage; LDGS= Low Digestible Grass Silage; STR= Straw*
c) *Standard error in parentheses*

4.3.5 Differences in MFE between the old and the new field

Ranges in slurry MFE were high for both the NEW (37–78%) and the OLD field (36–65%) (Table 4.7) and high standard errors show that there was a large variation in the MFE between replicates on both fields as is often observed in field experiments (Muñoz *et al*., 2004). Average MFE on the NEW field (56%) was higher compared to the OLD field (47%) (P=0.01). The average MFE of the NEW field is similar to the results of other grassland experiments with slit injection in the Netherlands (Van der Meer *et al*., 1987; Schils and Kok, 2003) and in line with present recommendations in the Netherlands that are based on the model of Sluijsmans and Kolenbrander (1977). After correction for ammonia losses MFE ranged from 47 to 88% on the NEW field and from 47 to 72% on the OLD field (data not shown) whereas Sørensen *et al*. (2003) found a range of 51 to 78% for cattle slurry applied to barley after correction for ammonia loss.

The total N uptake on the OLD field in this experiment was higher compared to the NEW field (Figure 4.3B, quadrant IV), reflecting the higher N delivery capacity. As the slope of both curves is exactly the same, it can be concluded that the response of N uptake to artificial fertilizer application was the same for the OLD and the NEW field. The response to slurry N however, was lower on the OLD field, as shown by the significantly lower average MFE value (Table 4.7) on the OLD field. This lower response to slurry N was in all probability caused by denitrification of slurry N as the wet soil conditions in spring were especially favorable for denitrification on the OLD field (Aulakh *et al*., 1991) and it is known that application of slurry tends to promote denitrification through the supply of readily available C (Whitehead, 1995). Another, but less likely, explanation for the lower MFE on the OLD field is a higher immobilization of slurry N compared to the NEW field as soils with relatively high SOM contents are assumed to have a larger and more active microbial population than soils with lower SOM (Dick and Gregorich, 2004). Microbial immobilization is greater with ammonium than with nitrate (Davidson *et al*., 1990) and slurry ammonium can cause a higher immobilization than fertilizer ammonium (Flowers and Arnold, 1983).

4.3.6 Differences in MFE between slurries

The experimental slurries showed a significantly higher average MFE compared to the commercial slurries (P<0.05) and experimental slurries from the high protein diets showed a significantly higher average MFE compared to slurries from low protein diets (P<0.05). A decrease in slurry N availability with a decreasing protein content of dairy cow diets has been observed in earlier experiments (Paul *et al*., 1998; Sørensen *et al*., 2003). There was no significant difference in MFE between slurries from high and low energy diets, indicating that the dietary energy content was not a decisive factor for slurry N availability. Sørensen *et al*. (2003) found significant relations between MFE and dietary fibre characteristics. These findings could not be confirmed in the present experiment, probably due to the large influence of the dietary protein surplus and the fact that only four different forages were used.

Average MFE of the slurries was proportional to the $N_{ammonium}$:N_{total} ratio (Figure 4.4) on both fields ($P=0.004$) but $N_{ammonium}$:N_{total} ratio explained only 34% of the variation in average MFE. C:N_{total} ratio of the slurries showed a slightly stronger - negative - relation with MFE ($P=0.001$, $R^2=0.42$), whereas the slurry NH_4-N content (g kg^{-1} DM) explained 50% of the variation in average MFE ($P<0.001$) (Figure 4.4). No significant difference in slope between the two fields was observed for any of the slurry characteristics. Despite the large variation between replicates, the described relations were also significant for the individual data and the commercial slurries fitted very well within these relations. The fact that the absolute ammonium content explains more of the variation in MFE compared to the $N_{ammonium}$:N_{total} ratio might be explained by the induced higher ammonium contents in case of the high energy diets as a result of the greater total feed intake per cow and subsequent higher N surpluses in the excreta. After correction for ammonia loss, the described relation between C:N_{total} ratio and MFE on the NEW field shows great similarity both in slope and intercept to the relation presented by Sørensen *et al.* (2003) in case of a field experiment with barley.

MFE of organic N ($MFE_{organic}$) showed very large variation between replicates (data not shown). Average $MFE_{organic}$ of the slurries varied from –31 to 61% on the NEW field and from –32 to 38% on the OLD field. There was no significant difference in $MFE_{organic}$ between high and low energy diets. In line with findings of many authors (Van Faassen and Van Dijk, 1987; Chadwick *et al.*, 2000; Van Kessel *et al.*, 2000) a significant negative relation ($P<0.05$) between $MFE_{organic}$ and the C:N_{org} ratio of the slurries was observed for both fields. The average value of 22% on the NEW field fell within the values reported for N availability of organic dairy manure from laboratory experiments with similar time periods, ranging from 12 to 51% for different soil types (Chae and Tabatai, 1986; Van Faassen and Van Dijk, 1987; Chadwick *et al.*, 2000). The negative average value of $MFE_{organic}$ on the OLD field (–1%) indicates a net immobilization of N. However, as described in Section 3.4 this low value is probably the result of denitrification of slurry ammonium and is therefore not a reliable estimate for organic N availability.

We conclude that even with these slurries that show a large range in C:N_{org} ratio, the relation between slurry C:N_{total} ratio and first-year N availability found by Sørensen *et al.* (2003) was confirmed on two grassland fields. As also for lactating cows the slurry C:N_{total} ratio is highly related to the protein content of the diet (Paul *et al.*, 1998; Külling *et al.*, 2001, Sørensen *et al.*, 2003) the results clearly indicate that reducing the protein content of dairy cow diets will result in a decrease of the first-year N availability of slurry. This differentiation needs to be taken into account in fertilization recommendation schemes.

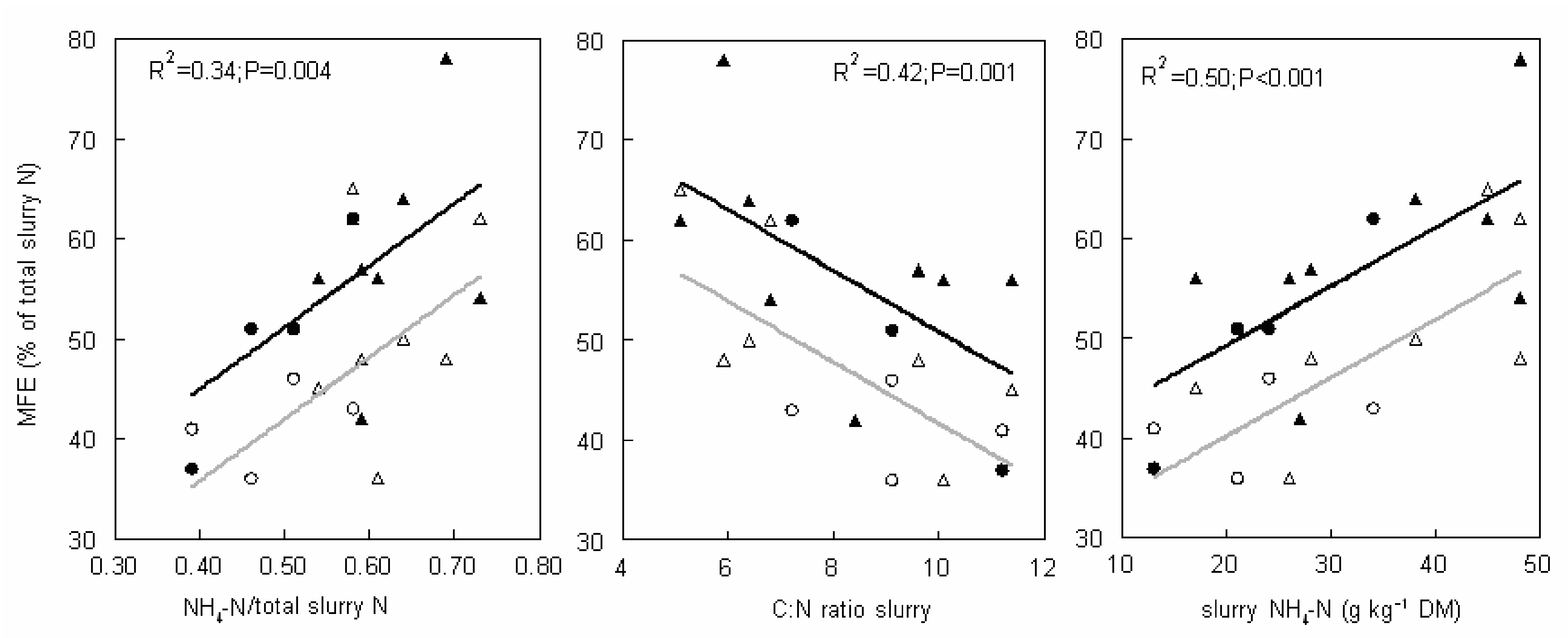

Figure 4.4 *Relation between the average mineral fertilizer equivalent (MFE) of experimental ((▲) NEW and (Δ) OLD) and commercial ((●) NEW and (○) OLD) cattle slurries on a NEW and OLD grassland and (A) the* $N_{ammonium}$:N_{total} *ratio of the slurry, (B) the C:*N_{total} *ratio of the slurry and (C) the ammonium (N-*NH_4*) content in DM of the slurry*

4.3.7 Long term effects

Model simulations showed that differences in slurry composition could lead to substantial differences in both soil organic C and N content with long-term application of 180 kg of slurry N ha^{-1}. The slurry with the highest C:N_{total} ratio (slurry no. 7) resulted in an increase in simulated SOC content in equilibrium state (200 years) in both soils (Table 4.8) while a decrease in SOC could be observed for the slurry with the lowest C:N_{total} ratio (slurry no. 2) on the OLD field (Table 4.8). These results are in agreement with findings of Paustian *et al.* (1992) and Hao *et al.*, (2003) who concluded after analysis of long-term experiments that differences in SOM could be explained by the rate of organic matter input and its composition. The estimated soil organic N content increased for all four situations up to approximately 9.8 Mg ha^{-1} with slurry no. 2 and 12.9 Mg ha^{-1} for slurry no. 7 for both soils (Table 4.8). These simulation results indicate a decrease of soil C:N ratio with long-term manure application for both slurries, in line with Sommerfeldt *et al.* (1988). The increase in soil organic N contributes to an increase of soil N mineralization. For all four situations, the estimated soil N mineralization ($NMIN_{soil}$) increased as a result of the increase of organic N in the soil. In the equilibrium state after 200 years $NMIN_{soil}$ was approximately 150 kg N ha^{-1} for slurry no. 2 and 180 kg N ha^{-1} for slurry no. 7 on both fields. This implies an increase of the yearly soil N mineralization as a result of slurry application of 50 kg N ha^{-1} for slurry no. 2 and 80 kg N ha^{-1} for slurry no. 7 on the NEW field, of which the largest part comes within the first 50 years.

The simulated time course of annual availability of inorganic N from slurry, slurry mineralization and soil mineralization is presented in Figure 4.5. The lower availability of inorganic and organic slurry N of the slurry with a high C:N_{total} ratio will be compensated by the increase of soil N mineralization only at the very long term (Figure 4.5). These results imply that, if ammonia losses with application can be limited, slurries with a low C:N_{total} ratio will give higher yields and a larger N utilization in the short and medium term, especially when taking into account that the higher yields obtained with this slurry type also might lead to a greater return of crop residues (Christensen and Johnston, 1997). However, this phenomenon is not represented in our simple model. On the other hand, Fauci and Dick (1994) concluded that long-term organic soil amendments increased biological activity in proportion to the amount of C added. De Goede *et al.* (2003) showed that the slurry type per se can have a substantial effect on the number of earthworms and the subsequent annual N mineralization. Such effects of organic amendments on soil biota and soil biological activity were not taken into account in our simple model, indicating that the long-term soil N mineralization might be underestimated for a slurry with a high C:N_{total} ratio in the current model evaluation. Furthermore, the simulated increase of SOC in the case of slurry with a high C:N_{total} ratio might lead to beneficial effects on especially soil structure, thus influencing aeration, infiltration and rootability leading to a positive effect on herbage productivity, not represented by the simulation model.

Table 4.8 *Initial and simulated equilibrium soil characteristics (0–25 cm) after long-term annual application [a] of two different slurries*

Field [b]	NEW			OLD		
	Initial State	*Equilibrium state*		*Initial state*	*Equilibrium State*	
		Slurry [c]: low $C{:}N_{total}$ ratio	*Slurry [c]: high $C{:}N_{total}$ ratio*		*Slurry [c]: low $C{:}N_{total}$ ratio*	*Slurry [c]: high $C{:}N_{total}$ ratio*
Soil org. C (Mg ha^{-1})	76	84	134	111	86	135
Soil org. N (Mg ha^{-1})	5.9	9.7	12.8	9.1	9.9	13.0
Soil $C{:}N_{total}$ ratio	12.3	8.3	10.2	11.8	8.3	10.2

a) An annual application of 180 kg slurry N ha^{-1} was assumed

b) Soil properties of the fields are described in Table 4.3.

c) Slurry characteristics are described in Table 2. For this long-term simulation, the slurry with the lowest (no. 2) and highest (no. 7) $C{:}N_{total}$ ratio were selected from the experiment

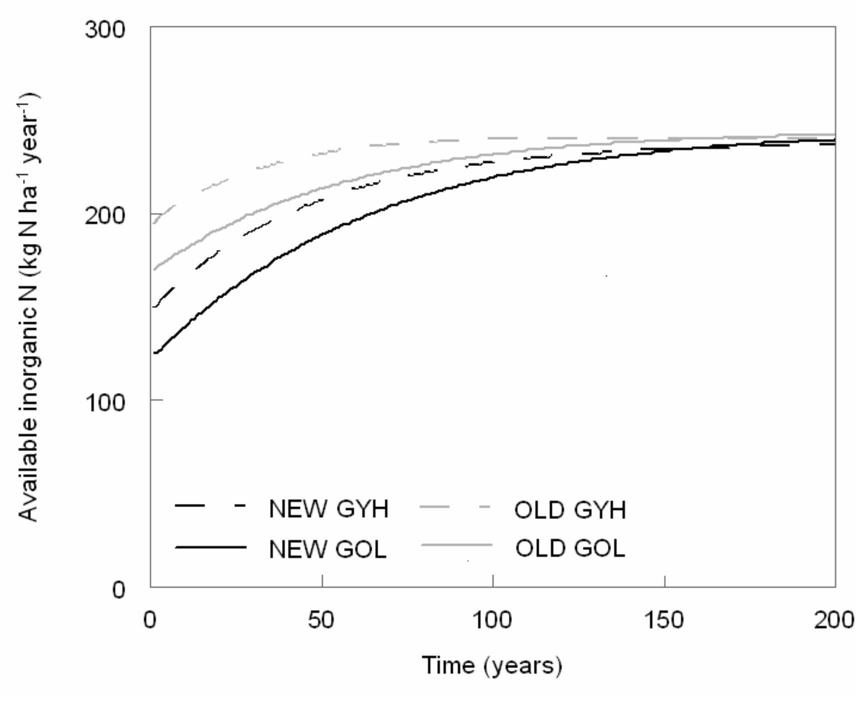

Figure 4.5 *Simulated time course of annual availability of inorganic N from slurry and soil together after long-term annual application of 180 kg N ha^{-1} from slurry with a low and a high $C{:}N_{total}$ on a NEW and an OLD grassland*

The simulation results indicate that on the short term and medium term, both N utilization and productivity will be lower with a slurry with a high C:N_{total} ratio, due to the fact that the residual slurry N is higher. Whether the overall N utilization of the total production system increases with low protein diets depends on a number of processes: 1) timing and rate of application of the slurry in combination with the fertilizer use 2) the actual achieved ammonia losses, both from housing and application and 3) the potential to utilize the residual slurry N. The final outcomes of these complex and interacting processes can not be answered from separated experiments but need to be addressed with integrated nutrient management models or on-farm research.

4.4 Conclusions

Slurry composition of dairy cows is affected by diet composition. After feeding non-lactating dairy cows diets with extreme high and low levels of energy and protein based on various forages (high and low digestible grass silages, maize silage and straw), variation in C:N_{total} ratio could be explained for 96% ($P=0.001$) by the combination of the crude protein and NDF content of the diet. The slurry C:N_{org} ratio was best related (78%) with the C:N ratio of the forage part of the diet ($P=0.004$)

A reduction of the dietary protein content has often been suggested to reduce N losses from the dairy system. In this study, the modelled ammonia N loss after field application was not positively related to the ammonium content of the slurries as a result of a negative relation between slurry DM and ammonium content. Thus, it may be difficult to reduce ammonia losses from field application of undiluted slurry by means of a reduction of the dietary protein content.

The first-year N availability of the slurries after slit-injection on grassland varied considerably. The two fields used in the experiment showed a difference in average N availability, possibly as a result of denitrification of slurry N during wet conditions in spring on the OLD field. This difference clearly demonstrates that N availability depends on soil-specific characteristics and timing of application, even within a given soil type. A reduction of the dietary protein content resulted in a significant decrease of the first-year N availability but N availability was not affected by the energy content of the diet. On both fields, N availability appeared to be positively related to the slurry ammonium content and $N_{ammonium}$:N_{total} ratio on the one hand and negatively to its C:N_{total} ratio on the other, all in a linear way. This was in line with a previous experiment by Sørensen *et al*. (2003) where barley was used as the test crop.

Model simulations demonstrated that the reduced first-year N availability of slurry with a high C:N_{total} ratio will eventually be compensated for by additional soil N mineralization due to an increased accumulation of soil N, but this will take tenths of years. Finally, the model simulations also suggest an increased soil carbon sequestration using slurries with a higher C:N_{total} ratio.

Chapter 5

Modelling the effect of nutritional strategies for dairy cows on the composition of excreta N

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Modelling the effect of nutritional strategies on excreta composition of dairy cows

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Abstract

For an integrated evaluation of the effect of nutritional strategies on the utilization and losses of N at dairy farms, reliable estimates of excreta production and composition are indispensable. To this end, a well-evaluated dynamic and mechanistic model of rumen functioning was extended with static equations that describe intestinal digestion to simulate the composition of dairy cow faeces and urine as a function of diet composition. The extended model predicts organic matter (OM), carbon (C) and nitrogen (N) output of both excreta products, classified in different components. Total N excretion was partitioned in three fractions, N_M *(immediately available)* N_E *(easily decomposable) and* N_R *(resistant), based on the C:N ratio of individual components. Forty different nutritional strategies for stall-fed dairy cows, covering diets with a wide range in protein content and OM digestibility, were evaluated with this model.*

The applicability of the model appears promising as the observed ranges in faecal and urinary composition were largely in line with values reported in literature. However, in particular for the prediction of the digestion in the LI and of the amount of non-urea-like urinary components, additional quantitative information on dietary effects may refine the model. Simulation results showed that nutrition can have a substantial effect on total N excretion and excreta composition, mainly as a result of differences in the level of N_M *excretion and the C:N ratio of the* N_R *fraction. Furthermore, it was shown that the type of OM excreted can vary considerably between different diets.*

A simplified simulation of degradation processes during the first four months of excreta storage produced average values and ranges of slurry characteristics that were in line with values reported in literature. The simulated variation in slurry characteristics suggested a strong variability in ammonia N losses from the slurry pit and a moderate variability in plant availability of slurry N. Further effort is required to integrate effects of storage conditions on the storage processes. It is concluded that the model can be a helpful tool to improve the utilization of N from field applied manure as well as to evaluate the effects of different nutritional strategies on the whole-farm N balance.

5.1 Introduction

Faecal and urinary N of dairy cows contribute to environmental pollution through the emission of ammonia and nitrous oxide to the air and through nitrate, ammonium and organic N emission to ground- and surface waters. Nutrition management is an important tool to control this environmental pollution (Tamminga, 1992). The total amount of N excreted in faeces and urine can be significantly reduced by lowering the dietary protein content (Castillo *et al.*, 2000; Kebreab *et al.*, 2002; Børsting *et al.*, 2003) without drastic consequences for milk production. As excessive feed N is mainly excreted with urine, a reduction of the dietary protein content will generally result in a more than proportional reduction of the urinary N excretion (Van Vuuren *et al.*, 1993; Kebreab *et al.*, 2002), which is the most volatile component. Through this effect, reductions in dietary protein result in significant reductions of gaseous N emissions (Paul *et al.*, 1998; Külling *et al.*, 2001; Misselbrook *et al.*, 2005).

However, N excretion is not exclusively determined by the level of protein in the diet. The main part of the feed ingested by the cow is degraded by microbes in the rumen and therefore feed digestion and the subsequent excreta composition depends to a large extent on the complex microbial processes occurring in the rumen. To minimize N excretion and maximize N utilization at the cow level, a correct balance of the supply of N and energy in the rumen is of large importance (Tamminga *et al.*, 1994; Dijkstra *et al.*, 1998). To improve the understanding, integration and prediction of microbial metabolism in the rumen several mechanistic models have been developed (Dijkstra *et al.*, 2002). These models take interactions and combined effects of energy and protein yielding nutrients into account. This quality gives these models the latent advantage of being able to explain additional details of consequences of nutritional strategies in comparison to current static feed evaluation systems (Bannink *et al.*, 2007).

Several nutritional strategies can be followed to improve N utilization of dairy cows in grassland-based dairy farms, such as a reduction of the N fertilization level (e.g. Peyraud & Astigarraga, 1998; Kebreab *et al.*, 2000), postponement of the cutting moment (e.g. Kebreab *et al.*, 2000), the use of low protein additional feeds like maize silage (e.g. Valk, 1994) or industrial by-products (e.g. Van Vuuren *et al.*, 1993) and the adjustment of concentrate composition (e.g. Børsting *et al.*, 2003). However, nutrition not only affects the utilization of N by the cow, but also the composition of the excreta and therefore it interacts with the major part of the processes at the farm level where N is converted and lost. Utilization of N from soil-applied dairy cow slurry has been shown to be affected by nutrition (e.g. Paul *et al.*, 1998; Sørensen *et al.*, 2003; Chapter 4). For this reason the evaluation of nutritional strategies should go beyond the cow level. For an integrated and profound evaluation of the effect of nutritional strategies on N utilization at farm level, qualification and quantification of excreta composition is a crucial step. Such an evaluation requires a realistic and detailed representation of the cow's digestive processes, taking into account the complexity of rumen functioning.

The main objective of this study is to present a model that is capable of evaluating the impact of nutritional strategies on N utilization at the farm level, without losing understanding of the complex digestion processes occurring at the cow level. For this purpose, an existing dynamic, mechanistic model of rumen function and subsequent nutrient availability (Dijkstra *et al.*, 1992; Dijkstra *et al.*, 1996) was extended with static equations that describe intestinal digestion. The extended model predicts organic matter (OM), carbon (C) and N output in different faecal and urinary components as a function of diet composition. With this model, excreta composition was simulated for 40 nutritional strategies of stall-fed dairy cows in grass silage based systems, covering a wide range in OM digestibility and dietary protein content. The various strategies included adaptations of the type of grass silage, reflecting differences in N fertilization level and cutting stage, type of grass silage replacement and the level of concentrate feeding. In addition, degradation processes during the first four months of excreta storage were simulated in a simplified way to quantify the effect of the nutritional strategies on the composition of field-applied slurry. Based on the simulations, the applicability of the model, the potential variation in excreta composition and its consequences for the composition, utilization and losses of slurry N during storage are evaluated.

5.2 Material & methods

5.2.1 General structure of the model

A schematic representation of the model is shown in Figure 5.1 and the principal symbols used are listed in Table 5.1. The dynamic and mechanistic model of rumen microbial fermentation processes of Dijkstra *et al.* (1992) was used to predict the outflow of undigested feed and microbial material from the rumen to the intestines (g day^{-1}) as a function of the chemical composition and rumen degradation characteristics (based on in-sacco experiments) of ingested feedstuffs and of the microbial activity. To obtain quantitative data on faecal composition, the rumen model was expanded with equations that describe the digestion of these rumen outflow components in the small and large intestine. These equations are described in detail in Section 5.2.2.

Table 5.1 *Abbreviations used in the model and assumed C and N contents of components*

Abbreviation	Description	% C	%N
Rumen model outflow and faecal components			
Am	Ammonia	0.000	0.824
As	Amylolytic microbial storage polysaccharides	0.444	0.000
EB	Endogenous biomass		
- EP	Endogenous protein	0.520	0.160
- EL	Endogenous lipids	0.750	0.000
Fd	Rumen degradable neutral detergent fibre	0.444	0.000
Fu	Rumen undegradable neutral detergent fibre	0.444	0.000
Ha	Hexose available to amylolytic microbes	0.444	0.000
Hc	Hexose available to fibrolytic microbes	0.444	0.000
Li	Lipids	0.750	0.000
LIMB	Large intestinal microbial biomass	0.472	0.135
Pd	Rumen-degradable protein	0.520	0.160
Ps	Rumen-fluid-soluble protein	0.520	0.160
Pu	Rumen-undegradable protein	0.520	0.160
RMB[a]	Rumen microbial biomass	0.472	0.135
Sd	Rumen-degradable starch	0.450	0.000
Sr	Rumen fluid-soluble starch	0.450	0.000
Va	Volatile fatty acids	0.450	0.000
Wr	Water-soluble carbohydrates	0.444	0.000
Urinary components			
Aa	Amino acids	0.35	0.16
Al	Allantoin	0.30	0.35
Cr	Creatine	0.41	0.24
Crn	Creatinine	0.43	0.37
Hi	Hippuric acid	0.60	0.08
Ua	Uric acid	0.36	0.33
Ue	Urea	0.20	0.47
Xa	Xanthine and hypoxanthine	0.42	0.39
Excreta components			
FEC	Faecal Endogenous components		
FFFC	Feacal Feed Fibre components		
FMC	Faecal Microbial components		
FOFC	Faecal Other Feed components		
UNUC	Urinary Non-urea-like components		
UUC	Urinary Urea-like components		

a) Rumen outflow RMB equals the sum of Ma and Mc described by Dijkstra et al. (1992).

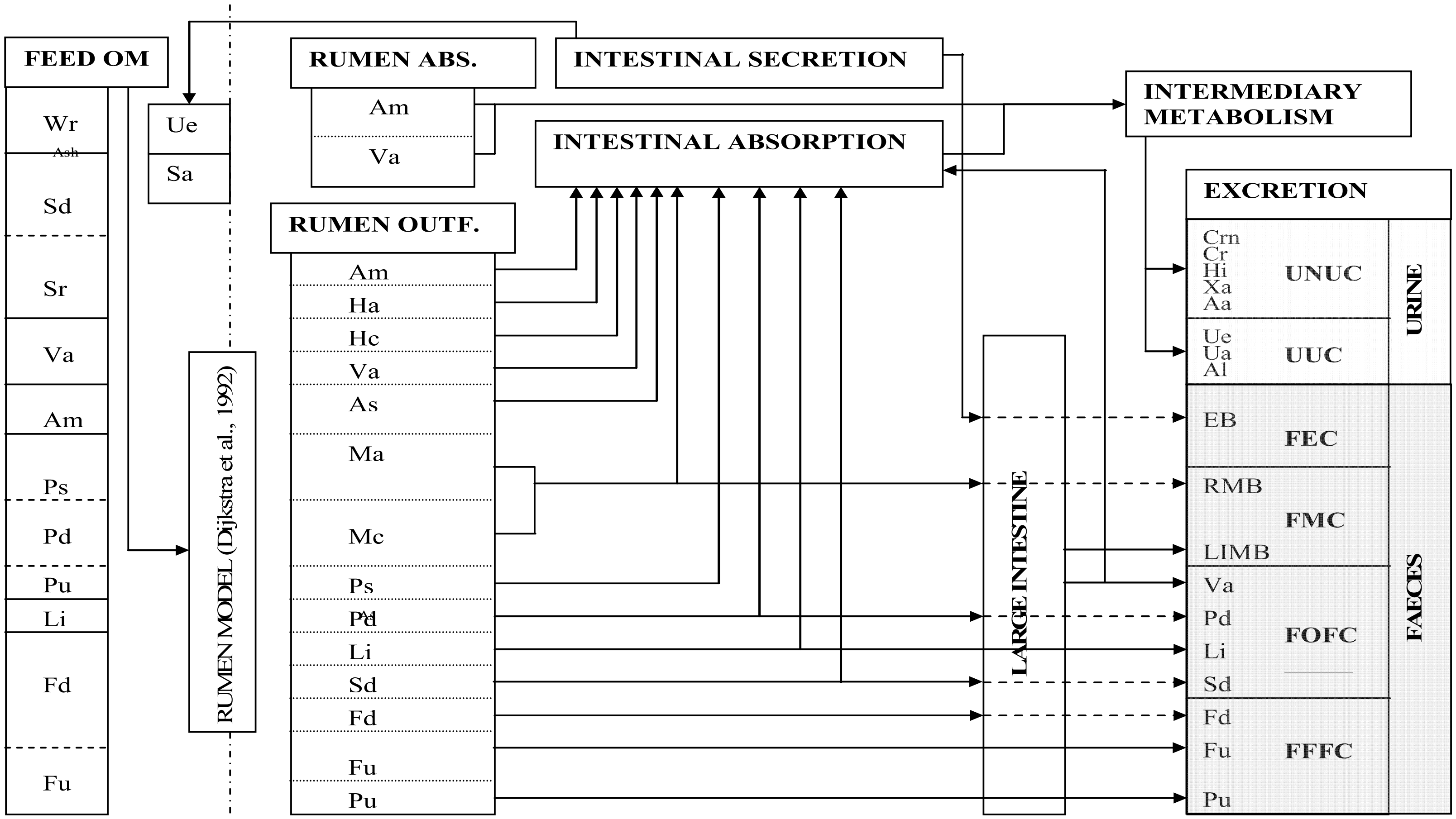

Figure 5.1 *Schematic representation of the model. Abbreviations are explained in Table 5.1. Rumen outflow is predicted by the model of Dijkstra et al. (1992). The arrows represent static equations that describe the fluxes (g day^{-1}) of different components through the digestive tract*

In the model, faecal excretion consists of 10 different components that are aggregated into four different categories as indicated in Figure 5.1, viz. faecal endogenous components (FEC), faecal microbial components (FMC), faecal feed fibre components (FFFC) and faecal other feed components (FOFC). The assumed C and N contents for the different components are given in Table 5.1.

A fixed milk composition of 40 g kg^{-1} fat, 33 g kg^{-1} protein and 46 g kg^{-1} lactose was presumed. Potential milk productions on the basis of total absorbed energy and on available nutrients (lipogenic, glucogenic and aminogenic) were simulated according to Dijkstra *et al.* (1996). The lowest of these four values was taken as the actual simulated milk production. Excretion of urinary N (g day^{-1}) was calculated by assuming zero N retention in the body according to:

$$N_{urine} = N_{feed} - N_{milk} - N_{faeces} \qquad (5.1)$$

In line with Bussink & Oenema (1998), N_{urine} was divided into urea-like urinary components (UUC) and non-urea-like components (UNUC, Figure 5.1). Urea N (Ue) was calculated as the difference of N_{urine} minus the sum of N in other urinary constituents of which the estimation procedure is described in Section 5.2.3.

5.2.2 Intestinal digestion and faecal excretion

Rumen undegradable fibre and protein (Fu and Pu) was assumed to be also indigestible in the intestines and therefore completely excreted with the faeces. Rumen degradable fibre (Fd) not digested in the rumen was assumed to be indigestible in the small intestine (SI). In the large intestine (LI) the digestion coefficient of Fd was based on the retention time of the material according to:

$$digFd_{LI} = kdFd_{rumen} / (kdFd_{rumen} + kp_{LI}) \qquad (5.2)$$

where $digFd_{LI}$ is the fraction of duodenal Fd outflow digested in the LI, $kdFd_{rumen}$ is the fractional degradation rate of ingested Fd in the rumen (% hr^{-1}, Table 5.3) and kp_{LI} (% hr^{-1}) is the fractional passage rate in the LI, estimated according to Mills *et al.* (2001):

$$kp_{LI} = 1/(-0.2 \times DMI + 13) \times 100\% \qquad (5.3)$$

where DMI is Dry Matter Intake in kg day^{-1}. The fraction of Sd outflow digested in the SI ($dig\ SD_{SI}$) was related to the percentage of starch escaping rumen fermentation, according to Nocek and Tamminga (1991):

$$digSd_{SI} = -0.728 \times RES + 0.879 \tag{5.4}$$

where *RES* is the total outflow of starch from the rumen, including microbial storage polysaccharides (As) as a fraction of total starch intake. The fraction of duodenal outflow starch digested in the LI ($digSd_{LI}$) was estimated according to:

$$digSd_{LI} = kdSd_{rumen} / (kdSd_{rumen} + kp_{LI}) \tag{5.5}$$

where $kdSd_{rumen}$ is the average fractional degradation rate of ingested Sd (% hr^{-1}, Table 5.3) in the rumen.

Microbial starch is assumed to be completely digested in the SI. Polysaccharide-free microbial organic matter (RMB) produced in the rumen was assumed to consist of protein (61%), nucleic acids (18%), lipid (16%) and cell walls (5%), based on Dijkstra *et al.* (1992). No distinction was made in the digestibility of N in the different components of RMB (protein, nucleic acids and cell walls) and the digestion of all N contained in the RMB was set at a constant value of 0.81 (Storm *et al.*, 1983). Storm *et al.* (1983) observed an OM digestibility in the SI of 0.74 for the total microbial matter, including microbial polysaccharides. As microbial polysaccharides are highly digestible, this digestion coefficient was adjusted to 0.67 for the polysaccharide-free RMB.

Excreted endogenous biomass (EB) was divided into protein (EP; digestive enzymes, desquamated epithelial cells, mucus) and lipids (EL; bile salts). EP excretion was based on a net loss of metabolic protein of 50 gram kg^{-1} ingested indigestible dry matter (Tamminga *et al.*, 1994). Endogenous lipid excretion was estimated to be 24 gram day^{-1} (Børsting *et al.*, 1992). The SI digestibility of rumen digestible feed protein (Pd) was set at 0.75 and that of feed, microbial and endogenous lipid at 0.90 (Palmquist *et al.*, 1993). Net lipid digestion in the LI was assumed to be zero, following observations of Drochner & Meyer (1991). The digestibility of feed protein and RMB in the LI was assumed to be constant at 10% of the duodenal outflow and the digestibility of endogenous protein was set at a significantly higher value of 40%, assuming that the endogenous protein is more easily fermented as it has not been subject to the digestive processes for the full length of the SI (Van Soest, 1994). The amount of fermentable organic matter (in hexose units) in the LI (FOM_{LI}) in gram day^{-1} was calculated according to:

$$\begin{aligned} FOM_{LI} &= 0.55 \times (Pd_{duddoutfl} - Pd_{manure}) + 0.55 \times (EP_{duodoutfl} - EP_{manure}) + \\ &0.55 \times (RMB_{duodoutfl} - RMB_{manure}) + (Fd_{duodoutfl} - Fd_{manure}) + (Sd_{duodoutfl} - Sd_{manure}) \end{aligned} \tag{5.6}$$

The assumption was made that protein provides 0.55 of pyruvate units per mol fermented substrate compared to hexose (Bannink *et al.*, 2006). Production of volatile fatty acids (Va) in the LI was assumed to be 0.7 gram per gram of FOM_{LI} (Demeyer & De Graeve, 1991). Assuming that the Va absorption rate (μmol cm^2 min^{-1}) of the LI is similar to that of the rumen (Ding *et al.*, 1998), it was estimated that 75% of the produced Va was aborbed,.The production of microbial N in the LI was estimated at 24 g kg^{-1} FOM, i.e. equal to that of the rumen (Tamminga *et al.*, 1994). As LIMB contains 0.135 g N kg^{-1} (Table 5.1), this implies a production of 178 gram of LIMB per kg FOM_{LI}.

5.2.3 Urinary N constituents other than urea

In general, urine of dairy cows contains only traces of free amino acids. Based on data of Bristow *et al.* (1992) it was assumed that only 2% of the urinary N consists of free amino acids (Aa). Hippuric acid (Hi) in ruminant urine is mainly a derivative of rumen microbial fermentation of phenolic cinnamic acids (Martin, 1982) and it has been shown that its relative contribution to the total N excreted can incidentally be very high (Nehring *et al.*, 1965; Bristow *et al.*, 1992). However, quantitative data on the effect of diet composition on Hi excretion are lacking and therefore an average contribution of 5% to total urinary N excretion (Bristow *et al.*, 1992) was assumed for Hi. Urinary creatinine (Crn) excretion is a relatively constant function of body weight (BW) and it was estimated at 29 mg kg^{-1} BW day^{-1} (Valadares *et al.*, 1999). Assuming a BW of 625 kg, this corresponds with a Crn-N excretion of 6.5 g day^{-1}. Cn-N excretion was estimated at 4.8 g day^{-1} based on the ratio between Crn and creatine (Cn) observed by Bristow *et al.* (1992). Xanthine/hypoxanthine (Xa) excretion is relatively small and was taken as 0.5% of total urinary N excretion (Bristow *et al.*, 1992). The excretion of purine derivatives (allantoin, xanthine, hypoxanthine and uric acid) has often been related to microbial synthesis in the rumen (Valadares *et al.,* 1999). In our model, the relationship reported by Susmel *et al.* (1993) was used to predict the total excretion of urinary purine derivatives:

$$UPD = 17.22 + 0.0082 \times RMP \qquad (5.7)$$

where *UPD* and *RMP* are the amounts of excreted urinary purine derivatives and rumen microbial protein outflow, respectively, in mg $day^{-1}kg^{-1}$ $BW^{0.75}$. After subtraction of Xa, the remaining UPD was divided into allantoin (Al) and uric acid (Ua), using a ratio of 85:15 (Bristow *et al.*, 1992; Valadares *et al.*, 1999).

5.2.4 From excreta to slurry composition

The most common system in the Netherlands is to store faeces and urine in a mixed slurry system for a period of approximately 4 months in the slurry pit. During this storage period the excreta and added bedding material with a relatively high C:N ratio are subject to both anaerobic and aerobic fermentation processes, affecting their composition. Manure OM is degraded (Whitehead & Raistick, 1993), manure C is lost (Kirchmann & Witter, 1992, Sørensen, 1998), urea-N and part of the organic N in manure are transformed into NH_4^+-N (Whitehead & Raistick, 1993; Sørensen, 1998, Sørensen *et al.,* 2003) and N losses occur through gaseous emissions (Smits *et al.*, 1995; Külling *et al.*, 2001; Misselbrook *et al.*, 2005a).

To quantify the effect of these processes on the final slurry composition after storage, it was assumed that all N in the urea-like components (UUC) was converted into NH_4^+-N. Based on results of Sørensen *et al.* (2003), the transformation of the (other) organic N into NH_4^+-N was assumed to be negatively related to the fibre content of the diet according to:

$$MIN_{organicN} = 50 - 0.075 \times NDF_{diet} (g \cdot kg^{-1} DM) \qquad (5.8)$$

where $MIN_{organicN}$ is the percentage of organic N (total excreted N - UUC N) that is mineralized and transformed into NH_4^+-N during storage.

As no quantitative data were found to differentiate C loss for diet or slurry characteristics, a fixed percentage of 13% was used to calculate the C loss during storage as found by Sørensen (1998) after 20 weeks. The percentage of slurry OM loss was assumed to be equal to the C loss as Kirchmann & Witter (1992) found no marked difference between OM and C loss. From the results of Külling *et al.* (2001) it was concluded that nitrous oxide emissions are negligible in slurry based systems compared to N losses with ammonia. Total ammonia N losses in the storage period include both emissions from the stable floor and the storage pit and were estimated to be 22% of the urea-N (Van Duinkerken *et al*., 2003). The use of bedding material was supposed to be 1 kg of sawdust (C:N ratio of 450) per cow per day.

5.2.5 Nutritional strategies

Forty different nutritional strategies, all based on stall-fed situations, were explored with the model. The various strategies included adaptations of the type of grass silage, type of grass silage replacement and the level of concentrate feeding (Table 5.2). High (HF) or low (LF) level of inorganic N fertilization, combined with an early (EC) or late (LC) cutting stage were considered to give four different spring cut silages, viz. HFEC, HFLC, LFEC, LFLC. The assumed chemical composition and rumen degradation characteristics of these silages are shown in Table 5.3. It was assumed that grass was fertilized before the first cut with dairy slurry (25 ton ha^{-1}) in combination with a high (100 kg N ha^{-1}) and a low level (50 kg N ha^{-1}) of inorganic fertilizer. A reduction of the fertilization level was expected to result in a decrease of the crude protein (CP) level and an increase in the content of water soluble carbohydrates (Wr) (Peyraud & Astigarraga, 1998). Postponement of the cutting moment (from 3000 to 4500 kg DM ha^{-1}) was expected to increase the NDF content and to decrease the crude ash content (Bosch *et al.*, 1992; Rinne *et al.*, 1997). Rumen protein degradation characteristics were estimated by regression formulas from Tamminga *et al.* (1991). For the EC silages the rumen undegradable NDF fraction (Fu) was estimated at 10% (Van Vuuren *et al.*, 1989; Bosch *et al.*, 1992, Bruinenberg *et al.*, 2004). Bosch *et al.* (1992) showed that with increasing NDF contents, Fu (both absolute and as a fraction of total NDF) increases and the fractional degradation rate of rumen-degradable fibre (kdFd) decreases. The Fu fraction of the LC silages was set at 25%, being the average value of two silages with similar NDF contents used by Bosch *et al.* (1992) and Bruinenberg *et al.* (2004). The fractional degradation rate of the LC silages was set at 65% of that of the EC silages based on the observed differences in kdFd between grass silages with high and low NDF contents in both experiments (Bosch *et al.*, 1992; Bruinenberg *et al.*, 2004).

Table 5.2 *Description of selected nutritional strategies*[abc] *and simulated average milk production*

No.	Strategy		*Milk production: Simulated average*	
			FPCM[f]	Feed N conversion
Grass silage type[d]				
4	HFEC[e]	F: 350 kg N ha^{-1} yr^{-1} C: 3000 kg DM ha^{-1}	30.6	0.25
	HFLC[e]	F: 350 kg N ha^{-1} yr^{-1} C: 4500 kg DM ha^{-1}	26.0	0.27
	LFEC[e]	F: 150 kg N ha^{-1} yr^{-1} C: 3000 kg DM ha^{-1}	28.7	0.31
	LFLC[e]	F: 150 kg N ha^{-1} yr^{-1} C: 4500 kg DM ha^{-1}	24.8	0.33
Grass silage replacement (forage composition)				
5	NO	100% grass silage	27.6	0.27
	MSIL	50% grass silage & 50% maize silage (MSIL)[e]	28.3	0.32
	STR	85% grass silage & 15% straw (STR)[e]	24.2	0.28
	PBP	85% grass silage & 15% pressed beet pulp (PBP)[e]	28.7	0.29
	POT	85% grass silage & 15% potatoes (POT)[e]	28.8	0.29
Concentrate level				
2	40%	60% forages and 40% concentrates (CONC)[e]	29.5	0.28
	20%	80% forages and 20% concentrates (CONC)[e]	25.6	0.29
Mean for all strategies			27.5	0.29

a) All combinations of the described strategies were simulated (n=40)
b) Dry Matter Intake (DMI) of the complete rations was estimated using the Dutch 'Dairy Cow Model' (Zom et al., 2002).
c) Concentrate composition was assumed to be constant
d) Based on differences in fertilization level (F) and cutting moment (C): HFEC = high fertilization and early cut; HFLC = high fertilization and late cut; LFEC = low fertilization and early cut; LFLC = low fertilization and late cut.
e) Characteristics of the feedstuffs are given in Table 5.3
f) FPCM = Fat and Protein Corrected Milk (assumed composition: 4.00% fat, 3.32% protein and 4.60% lactose)

The composition of concentrate feed was based on an arbitrarily chosen widely-used concentrate feed produced by a Dutch company. Chemical composition of the concentrate ingredients, straw (STR) and industrial by-products (pressed beet pulp, PBP; potatoes, POT) were based on Dutch standards (Anon., 2005a) (Table 5.3). Chemical composition of the maize silage (MSIL) was taken as the Dutch average for 2004. Rumen degradation characteristics were estimated from reports on in-sacco experiments for concentrate ingredients (Tamminga *et al.*, 1990; Van Straalen, 1995), MSIL (Klop & De Visser, 1994), STR (Wheeler *et al.*, 1979, Oosting, 1993; Sinclair *et al.*, 1993), PBP (Tamminga *et al.*, 1990; De Visser *et al.*, 1991; DePeters *et al.*, 1997) and POT (Van Straalen, 1995; Offner *et al.*, 2003) (Table 5.3).

Table 5.3 *Chemical composition, rumen degradation characteristics (RDC) and feed evaluation values (FEV) of the feedstuffs used*

Feed-stuff	Chemical composition (g kg^{-1} DM)											RDC (% hr^{-1})			FEV (kg^{-1} DM)		
	Ash	*Fd*	*Fu*	*Sr*	*Sd*	*Wr*	*Ps*	*Pd*	*Pu*	*Li*	*Fp*[a]	*kdFd*	*kdPd*	*kdSd*[b]	*NEL*[c] *(MJ)*	*DVE*[d] *(g)*	*OEB*[d] *(g)*
HFEC	118	417	46	0	0	50	139	63	16	45	102	4.5	6.0	n.a.	6.34	78	76
HFLC	102	404	135	0	0	100	104	42	19	35	58	3.6	4.3	n.a.	5.83	69	26
LFEC	118	423	47	0	0	110	93	35	18	45	109	3.6	3.7	n.a.	6.01	66	15
LFLC	102	413	138	0	0	130	69	24	17	35	71	3.0	2.5	n.a.	5.66	54	-14
MSIL	44	287	135	160	199	0	44	18	13	25	75	1.9	4.4	8.5	6.47	48	-26
STR	86	497	317	0	0	25	13	18	18	26	0	3.2	1.0	n.a.	3.51	12	-31
PBP	74	578	30	0	0	142	14	77	7	7	70	7.9	6.6	n.a.	7.33	104	-69
POT	63	180	20	273	330	0	15	82	5	1	30	10.0	7.5	9.1	7.23	57	1
CONC	92	305	77	93	70	146	62	102	8	45	0	8.5	7.3	11.0	7.17	104	7

a) FP = Fermentation Products (assumed composition: 60% Lactic Acid, 30% Acetic Acid, 5% Propionic Acid and 5% Butyric Acid)

b) n.a. = not available

c) NEL = Net Energy Lactation

d) DVE = True Protein Digested in the Small Intestine, OEB = Degraded Protein Balance, according to Tamminga et al. (1994).

The required input for the rumen fermentation model was completed as described below. Dry matter intake (DMI) of the complete rations was estimated using the Dutch 'Cow Model' (Zom *et al.*, 2002). Rumen fractional passage rates for fluid (kpf) and solid particles (kps) in % hr^{-1}, were calculated according to Van Straalen (1995):

$$kpf = -3.40 + 1.224 \times DMI - 0.030 \times DMI^2 + 5.93 \times pR \tag{5.11}$$

$$kps = pR \times (1.74 + 0.15 \times DMI) + (1 - pR) \times 10.1 - 0.96 \times DMI + 0.037 \times DMI^2) \tag{5.12}$$

where DMI is dry matter intake in kg day^{-1} and pR is the fraction of roughage in the diet. Rumen volume (RV; liter) was estimated as:

$$RV = 47.86 + 1.759 \times DMI \text{ (Dijkstra, personal communication)} \tag{5.13}$$

The average rumen pH was set at 6.0 for diets with 100% EC grass silages and a high concentrate level. For the other strategies the following adjustments for pH were made (Dijkstra, personal communication): low concentrate level: +0.3, LC silages: +0.1, MSIL: –0.05, STR: +0.1, PBP: –0.1, POT: –0.05. The minimum daily pH (PM) and the time below a critical pH for reduced fibre digestion (TF in hr/24 hr) were calculated as:

$$PM = pH - (pH \times 0.05) \text{ (Mills et al., 2001)} \tag{5.14}$$

$$TF = (-10.59 \times pH) + 76.82 \text{ (Erdman, 1988)} \tag{5.15}$$

5.3 Results

5.3.1 Ranges in simulated excreta composition

Simulated intake, dietary characteristics and digestion coefficients showed large variation between nutritional strategies (Table 5.4). Obviously, this variation resulted in differences between nutritional strategies in energy and nutrient availability for milk production. Simulated FPCM production ranged from 19.1 to 33.8 kg day^{-1}, whereas simulated total excretion of OM varied between 3.7 and 6.3 kg day^{-1} (Table 5.5), as a result of a range in apparent OM digestibility from 70 to 82% (Table 5.4).

Table 5.4 *Mean values and ranges of intake, diet composition, simulated digestion coefficients, simulated milk production and feed N conversion of 40 nutritional strategies[a] for dairy cows*

Description of diets		Mean ± s.d.	Range
- Intake	Dry Matter (kg DM day^{-1})	19.6 ± 1.7	16.0–22.4
	Organic Matter (kg OM day^{-1})	17.7 ± 1.6	14.5–20.3
	Nitrogen (g N day^{-1})	509 ± 106	311–730
	Neutral Detergent Fibre (kg NDF day^{-1})	9.0 ± 0.5	8.0–10.1
	OEB[b] (g day^{-1})	268 ± 402	–292–1182
- Composition	OM (g kg^{-1} DM)	903 ± 10	888–924
	Crude Protein (g kg^{-1} DM)	152 ± 26	107–209
	Neutral Detergent Fibre (g kg^{-1} DM)	463 ± 37	404–547
	Net Energy Lactation (MJ kg^{-1} DM)	6.4 ± 0.3	5.7–6.8
Simulation results			
- Digestion	Digested OM (%)	75 ± 3	70–82
	Digested N (%)	69 ± 5	59–78
	Digested NDF (%)	68 ± 7	56–83
- Production	Milk Production (kg FPCM[c] day^{-1})	27.5 ± 3.6	19.1–33.8
- feed N conversion	Milk N / ingested N (%)	29 ± 4	23–37

a) Nutritional strategies and feed characteristics are described in Tables 5.2 and 5.3.
b) OEB = Degraded Protein Balance according to Tamminga et al. (1994)
c) FPCM = Fat and Protein Corrected Milk (assumed composition: 4.00% fat, 3.32% protein and 4.60% lactose)

Both simulated faecal and urinary OM excretion showed considerable variation (Table 5.5). Total N excretion differed with a factor 2.6 between nutritional strategies. The simulated C:N ratio of the total excreta was highly variable (3.4–10.6, Table 5.5). Simulated faecal N excretion was relatively constant (128–177 kg N day^{-1}) and the faecal C:N ratio was quite variable, while urinary N excretion showed a large variation

(81–388 kg N day^{-1}) and urinary C:N ratio was almost constant (Table 5.5). The major part (on average 61%) of the OM was excreted as FFFC, while the largest part (on average 48%) of the N excretion was covered by UUC. The undigested feed components (FFFC and FOFC) showed a considerable range in C:N ratio, whereas the C:N ratio of the other components (UUC, UNUC, FEC and FMC) was much less variable. The distribution of faecal N excretion over the different components showed only a small variation: FFFC (28 ± 2%), FOFC (6 ± 2%), FMC (50 ± 2%) and FEC (16 ± 1%). The simulated percentage of urinary N excreted with UNUC ranged between 10 and 22%.

Table 5.5 *Mean values and ranges of simulated faecal and urinary OM and N excretion, distribution of excretion between different components*[a] *and C:N ratio of components for 40 nutritional strategies*[b] *for dairy cows*

	OM excretion (g day^{-1})		N excretion (g day^{-1})		C:N ratio	
	Mean ± s.d.	*Range*	*Mean ± s.d.*	*Range*	*Mean ± s.d.*	*Range*
Urine	606 ± 232	245–1094	211 ± 84	81–388	0.9 ± 0.0	0.9–1.0
Faeces	4469 ± 771	3112–5796	154 ± 13	128–177	13.4 ± 2.0	9.6–16.8
Total	5075 ± 760	3742–6275	365 ± 92	211–558	6.6 ± 1.8	3.4–10.6
Distribution of excretion (% of total excretion)					C:N ratio	
UUC	8.1 ± 3.6	3–17	48.2 ± 8.9	29–64	0.5 ± 0.0	0.4–0.5
UNUC	4.0 ± 1.4	2–8	7.5 ± 0.3	7–8	3.9 ± 0.4	2.9–4.6
FEC	3.0 ± 0.3	3–4	7.0 ± 1.9	4–11	3.3 ± 0.0	3.3–3.3
FMC	18.4 ± 3.0	16–25	22.0 ± 3.8	15–30	5.6 ± 0.1	5.3–5.8
FFFC	61.4 ± 7.8	43–72	12.7 ± 3.0	8–19	32.6 ± 7.5	18.8–46.9
FOFC	5.0 ± 0.9	3–7	2.7 ± 0.8	1–4	15.3 ± 2.4	11.7–21.2

a) UUC = Urinary Urea-like Components, UNUC = Urinary Non-Urea-like Components, FEC = Faecal Endogenous Components, FMC = Faecal Microbial Components, FFFC = Faecal Feed Fibre Components, FOFC = Faecal Other Feed Components

b) Nutritional strategies and feed characteristics are described in Table 5.2 and 5.3.

Based on their C:N ratio, the excreta components were divided into three different fractions representing their availability of N following manure application to crops (N_M, N_E and N_R, Sluijsmans & Kolenbrander, 1977) (Table 5.6). The immediately available fraction (N_M) is represented by UUC with a C:N ratio < 1. On average, 48% of the excreted N was present in this fraction, ranging from 29 to 64%. The easily decomposable fraction (N_E) consists of all manure components with a C:N ratio between 2 and 6, being UNUC, FEC and FMC and covered on average 37% (range 27–49%) of the excreted N. The resistant N fraction (N_R) comprises the undigested feed components

FOFC and FFFC, with a high but variable C:N ratio (range 12–47). This last fraction averaged to 15% (range 10–22%) of the total excreted N.

The OM excretion was divided into fibre (FFFC) and non-fibre (OM_{NF}) components (Table 5.6). Within the fibre components, a distinction was made between potentially rumen digestible (OM_{RDF}) and rumen indigestible material (OM_{RIF}) as this distinction might reflect differences in the degradability of manure organic material during storage and after application to soil. On average, 39% of the OM was excreted with the non-fibre fraction but with a considerable range (28 to 57%). The average fraction of potentially rumen digestible fibre in OM (OM_{RDF}, 21%) was half the size of the rumen indigestible fibre fraction (OM_{RIF}, 40%), but OM_{RDF} amounted up to 36% for diets with the highest rumen fractional passage rates.

Table 5.6 *Proportional composition (%) of OM[a] and N[b] in dairy cow excreta after simulation of 40 nutritional strategies[c]*

OM excretion (%)			
Fraction	Components[d]	Mean	Range
OM_{NF}	UUC, UNUC, FEC, FMC, FOFC	39 ± 8	28–57
OM_{RDF}	FFFC (Fd)	21 ± 7	10–36
OM_{RIF}	FFFC (Fu +Pu)	40 ± 9	26–58
N excretion (%)			
Fraction	Components[d]	Mean	Range
N_M	UUC	48 ± 9	29–64
N_E	UNUC, FEC, FMC	37 ± 6	27–49
N_R	FOFC, FFFC	15 ± 3	10–22

a) OM_{NF} = Non-Fibrous Organic Matter, OM_{RDF} = Rumen Digestible Fibre, OM_{RIF} = Rumen Indigestible Fibre.

b) N_M = Immediately available N (C:N ratio <1), N_E = Easily decomposable N (C:N ratio 2–6), N_R = Resistant N (C:N ratio >10)

c) Nutritional strategies and feed characteristics are described in Table 5.2 and 5.3.

d) Description of components in Table 5.5.

5.3.2 Effects of nutritional strategies on excreta composition and milk output

The variation in total N excretion is mainly reflected in the N_M fraction (Fig 2). The simulation results showed a strong decrease of N_M excretion when N fertilization is reduced from a high (HF; >300 kg N year^{-1}) to a low (LF; ~150 kg N year^{-1}) level whereas simulated milk output reduced only slightly (Table 5.2). An extended growing period of the silage grass (EC versus LC) decreased N_M excretion even further (Fig 2), due to a reduced DMI on the one hand and a decreased protein content in silage on the other hand, but at the expense of a larger reduction in milk output (Table 5.2).

The inclusion of maize silage in the diet strongly reduced simulated N_M excretion and had a positive effect on milk output, inducing a large increase in the conversion efficiency of feed N into milk N (Table 5.3). The inclusion of 15% straw in the diet markedly reduced DMI and N intake, resulting in a lower N_M excretion and a strong reduction of milk output. The inclusion of low protein feeds (PBP, POT) in the diet increased milk output and the conversion efficiency of feed N into milk N (Table 5.2), but had only a small reducing effect on N_M excretion. The decrease was smaller than expected due to the high DM and N intake with these diets.

In contrast to the large variation in N_M excretion, simulated variation in N_E and N_R excretion was small. The strategies that combine a high DMI with a relatively high rumen degradability of the carbohydrate fractions (EC silages, PBP, CONC 40%) showed only a slightly higher N_E excretion, probably as a result of an increased microbial synthesis either in the rumen or in the LI. An important explanation for the small range in N_R excretion might be found in the procedure to estimate the rumen degradation characteristics of protein in grass silages, resulting in small differences in the Pu fraction of grass silages (Table 5.3). As the N_R excretion appeared to be rather constant, the variation in C:N ratio of the N_R fraction (Figure 5.2) can be attributed to differences in C (OM) excretion. In case of diets with LC or maize silage, the high C excretion was induced by a high Fu fraction of the diet. In case of diets with a high concentrate level (CONC 40%) the high C excretion was induced by a reduction of the ruminal NDF digestion as a result of high rumen fractional passage rates and low rumen pH.

A high total OM excretion was induced either by a high DMI (CONC 40%, PBP, POT), a low OM digestibility (LC silages), or a combination of both (MSIL, Figure 5.3). The reducing effect of a low concentrate level (CONC 20%) and the use of straw (STR) on total OM excretion can be ascribed to the relatively low DMI with these strategies. Diets with the highest urinary excretion (HFEC, NO, PBP, POT, 40% CONC) showed the highest OM_{NF} excretion. The excretion of fibre OM (sum of OM_{RIF} and OM_{RDF}) is directly determined by the amount of undigested NDF and was highest for LC silages, MSIL and 40% CONC. The percentage of OM_{RDF} clearly reflects the efficiency of rumen NDF digestion. The lower DMI with the STR and 20% CONC diets indicates a more efficient rumen digestion of potentially rumen degradable NDF as a result of a lower fractional rate of rumen passage and a higher pH.

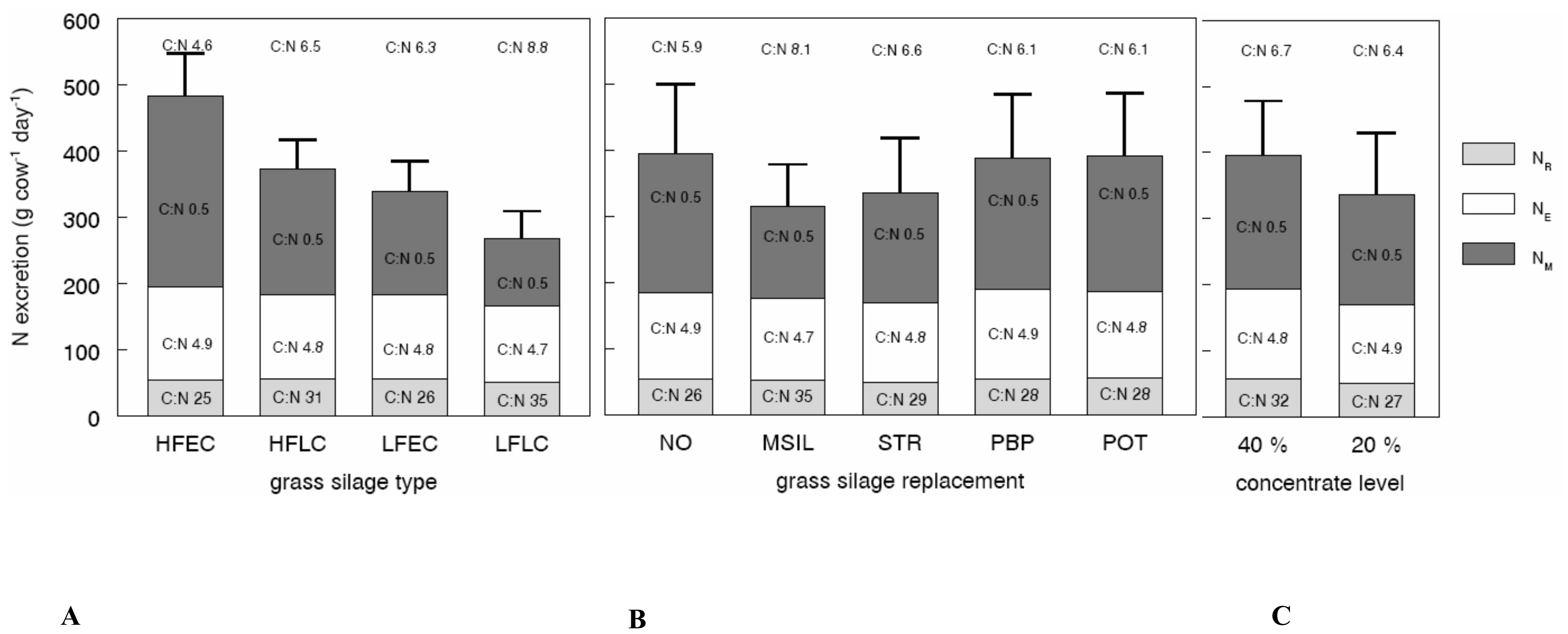

Figure 5.2 *Simulated N excretion divided in three different fractions as affected by nutritional strategy, the C:N ratio of these fractions and the C:N ratio of the total excreta. The excreta fractions represent* N_M *(immediately available N),* N_E *(easily decomposable N) and* N_R *(resistant N) as described in Table 5.6. The bars represent average values for all strategies with a given grass silage type (A, n=10), grass silage replacement (B, n=8) and concentrate level (C, n=20), as described in Table 5.2*

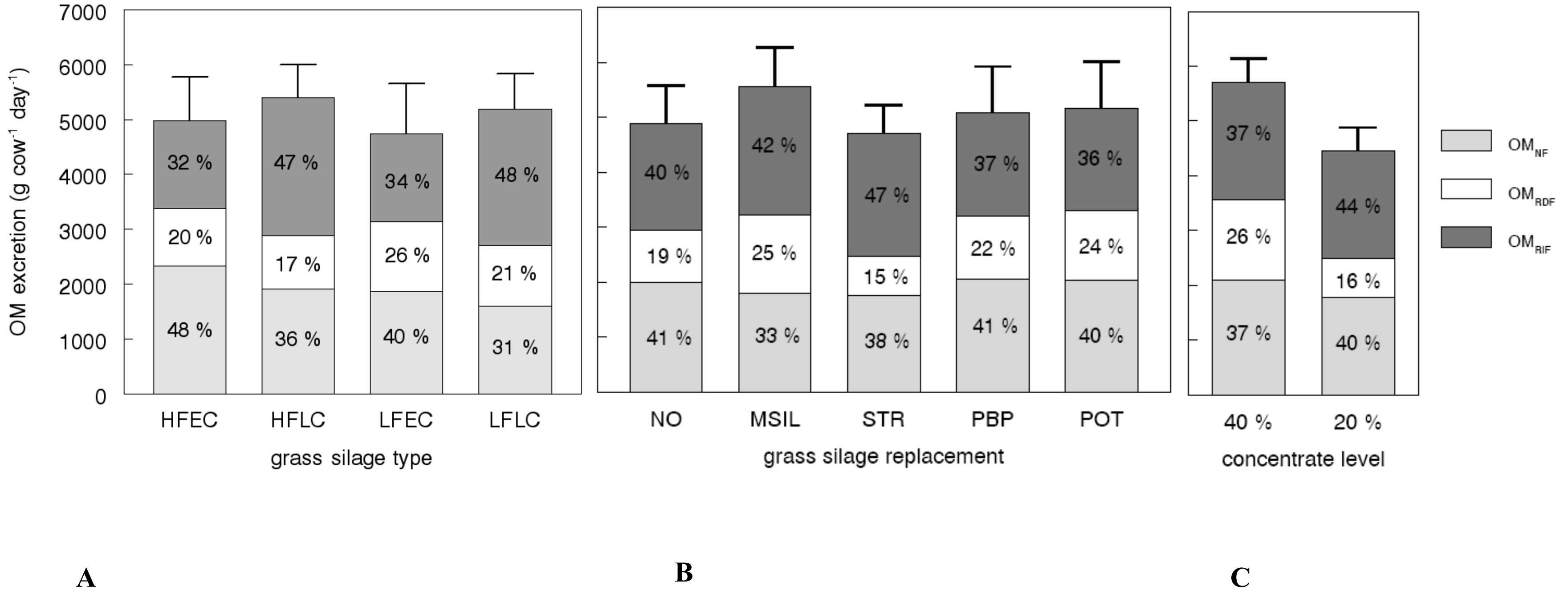

Figure 5.3 *Simulated OM excretion divided in three different fractions as affected by nutritional strategy. The excreta fractions represent* OM_{NF} *(non fibrous OM),* OM_{RDF} *(rumen digestible fibre) and* OM_{RIF} *(rumen indigestible fibre) as described in Table 5.6. The bars represent average values for all strategies with a given grass silage type (A, n=10), grass silage replacement (B, n=8) and concentrate level (C, n=20) as described in Table 5.2*

5.3.3 Simulated slurry composition

The simulated percentage of slurry N present in ammonium (N_M) after four months of storage was on average 52%, with a considerable variation between diets (range 34–65%, Table 5.7). Simulated total N content of the slurries was on average 61 g kg^{-1} OM (range 38–98) and the largest part of the variation was caused by variation in the simulated NH_4-N content (14–64 g kg^{-1} OM). The variation in simulated organic N content was considerably smaller (23–35 g kg^{-1} OM, Table 5.7). Both C:N_{total} ratio (4.4–11.9) and C:$N_{organic}$ ratio (12.4–19.3) showed a large variation. The simulated N loss with ammonia per cow was on average 37 g day^{-1}, but ranged from 11 to 73. These losses accounted for 9.7% (range 5.1–13.3) of the total excreted N (Table 5.7). Lowest slurry organic N contents were simulated for diets based on LC silages (HFLC, LFLC), maize silage (MSIL) and a high use of concentrates (40% CONC, Fig 4). The highest inorganic N contents were simulated for diets based on grass silage HFEC and the lowest values for diets based on grass silage LFLC and maize silage (MSIL).

Table 5.7 *Mean values and ranges of simulated slurry composition after 4 months of storage and simulated ammonia losses for 40 nutritional strategies*[a] *for dairy cows*

Slurry characteristic	Mean ± s.d.	Range
C:N_{total}	7.7 ± 1.9	4.4–11.9
C:$N_{organic}$	15.8 ± 1.8	12.4–19.3
NH_4-N : Total N (%)	52 ± 8	34–65
Total N (g kg^{-1} OM)	61 ± 15	38–98
NH_4-N (g kg^{-1} OM)	33 ± 13	14–64
Organic N (g kg^{-1} OM)	29 ± 3	23–35
Total ammonia loss during storage		
- g N day^{-1}	37 ± 17	11–73
- % of excreted N	9.7 ± 2.1	5.1–13.3

a) Nutritional strategies and feed characteristics are described in Table 5.2 and 5.3

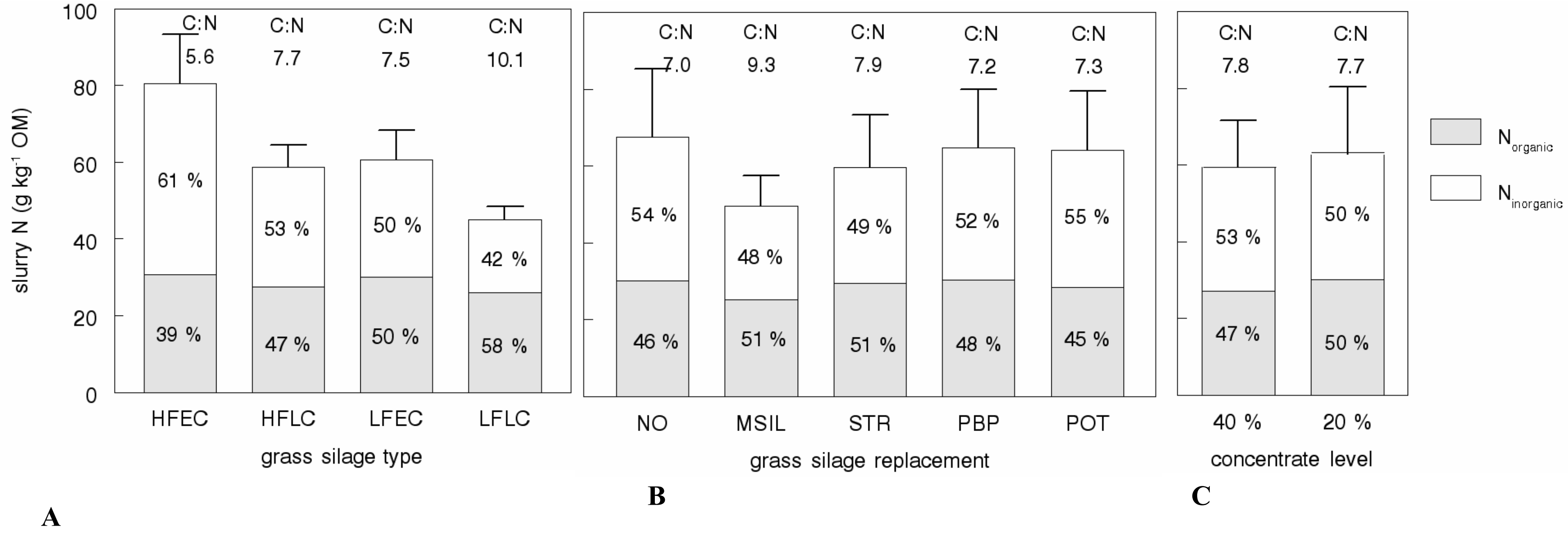

Figure 5.4 *Simulated total, organic and inorganic slurry N content after 4 months of storage and the simulated slurry C:N$_{total}$ ratio as affected by nutritional strategy. The bars represent average values for all strategies with a given grass silage type (A, n=10), grass silage replacement (B, n=8) and concentrate level (C, n=20) as described in Table 5.2*

5.4 Discussion

5.4.1 Evaluation of the selected nutritional strategies

Nutritional strategies to reduce excessive N excretion to the environment are often aimed at an improvement of the feed N conversion. In this study, the selected strategies were aimed at an increase of the feed N conversion compared to the basic situation where highly fertilized early cut grass silage (HFEC) is fed as the sole forage. Simulated feed N conversion indeed was higher for all strategies that included an adaptation of the silage type and/or a replacement of grass silage (Table 5.2). In line with earlier observations, reducing the fertilization level of grass silage (e.g. Peyraud & Astigarraga, 1998; Kebreab *et al.*, 2000) and the inclusion of maize silage (e.g. Valk, 1994) showed a strong potential to increase feed N conversion. The other strategies showed only moderate effects as a result of a decreased milk production (LC silages, straw) or an increased feed intake (PBP and POT). The average simulated feed N conversion was slightly higher than reported by Chase (2003) after reviewing 62 research papers on N utilization of dairy cows (29 versus 27%) but the range was considerably smaller (23–36% versus 16–45%).

To obtain a large range in the dietary protein level, the concentrate composition was not adjusted for the protein level of the forages. This resulted incidentally in low dietary crude protein contents and rumen degradable protein balances (Table 5.4). Furthermore, in 60% of the cases, the simulated milk production was higher than expected from the DVE supply (Tamminga *et al.*, 1994). Still, aminogenic nutrients were never predicted to be in short supply and milk production (FPCM) was limited by the availability of energy in most of the situations (n=38) or incidentally by glucogenic nutrients (n=2). Furthermore, the range in dietary protein content (Table 5.4) is similar to the range Chase (2003) reported (102 to 246 g kg^{-1} DM) and therefore the simulated nutritional strategies might be interpreted as a realistic representation of diets for mid-lactation dairy cows with respect to the dietary protein content. For high-yielding early lactation cows, however, several of the simulated diets will probably result in a shortage of either glucogenic or aminogenic nutrients. In practice, the selected forages will often be supplemented with protein to avoid a reduction of milk (protein) production in these cows and therefore the observed range in dietary protein content is likely to be levelled off then.

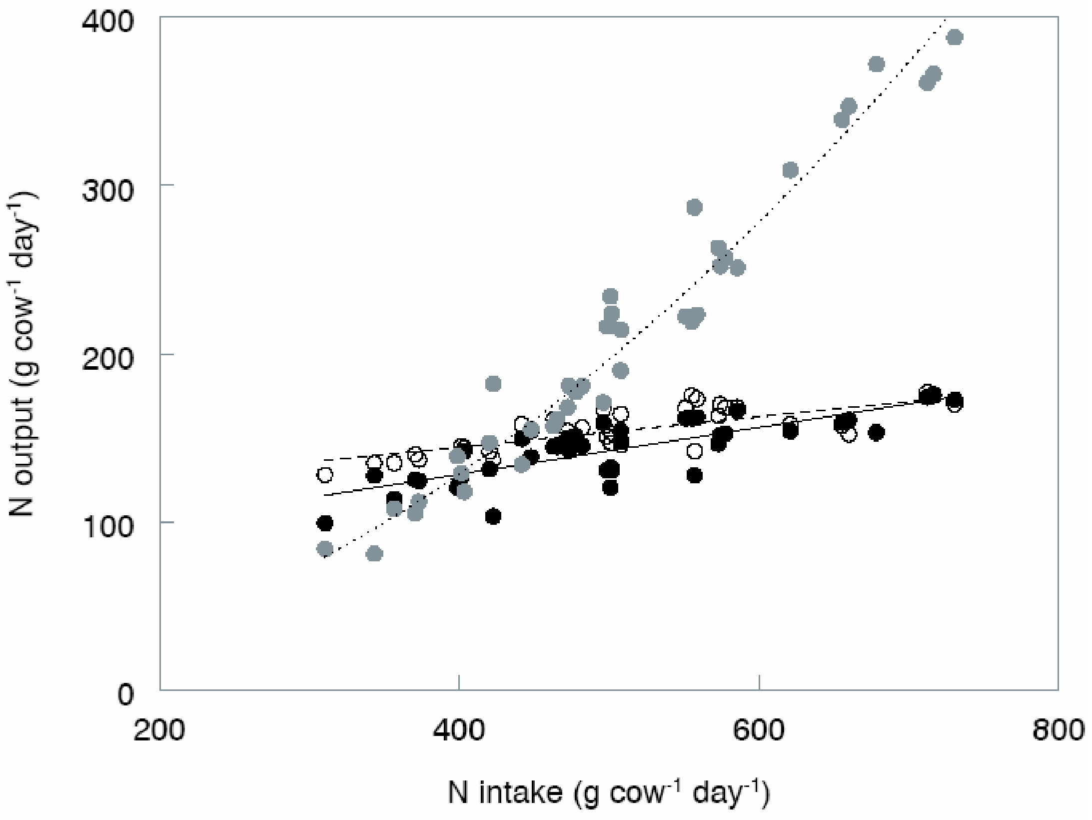

Figure 5.5 *Simulated relation between total N intake (g day^{-1}) and the output of N (g day^{-1}) with (●) milk (○) faeces and (●) urine for 40 nutritional strategies*

5.4.2 Accuracy of the simulation of excreta composition

Faecal excretion

Several authors have shown that an increase in N intake results in a small and linear increase of excretion of faecal N and milk N combined with an exponential increase in the excretion of urinary N (Castillo *et al*, 2000; Kebreab *et al*., 2001). Our simulation data reproduce the same pattern (Figure 5.5). The average level of faecal N excretion (154 g day^{-1}) is well in line with experimental data of Wilkerson *et al*. (1997), Castillo *et al*. (2000) and Kebreab *et al*. (2001). However, the simulated range in faecal N excretion is smaller than observed in some of these trials. The small variation in faecal N excretion can partly be attributed to the small range in Pu fraction of the forages. The Pu fraction of the grass silages, estimated according to regression equations by Tamminga *et al*. (1991) showed a limited variation (16–19 g kg^{-1} DM, Table 5.3) whereas the variation in Pu fractions actually observed in the study of Tamminga *et al*. (1991) ranged from 7–29 g kg^{-1} DM. Other experiments showed that variation in the indigestible protein fraction of individual grass silages may be even larger (Von Keyserlingk *et al.*, 1996; Bruinenberg *et al.*, 2004). The Pu fraction is fully excreted with faeces and it determines directly the amount of N excreted with FFFC. The simulated N excretion with the FFFC fraction for the selected strategies showed a limited variation of only 40–48 g N day^{-1} (data not shown). When more variation in Pu would have been assumed, this range would have been much larger, directly implying a larger range in total faecal N and N_R excretion.

The percentage of faecal N excreted with FFFC (24–32%, data not shown) is slightly higher than measured fractions of NDF-N in faeces by Sørensen *et al.* (2003, 14–21%) and Powell *et al.* (2006, 18–29%) after feeding a large range of diets to dairy cows. The simulated proportion of faecal N being present in microbial material ranged from 47 to 55% and was slightly lower than reported values of 70% by Robinson & Sniffen (1985), 53–73% by Robinson *et al.* (1987), and 61% by Larsen *et al.* (2001). Mason *et al.* (1981a) stated that the main components of the faecal water soluble N have their origins in intestinal excretion. In our study, the faecal N contained in endogenous material (FEMC) amounted up to 13–19%, being of similar magnitude as the fractions of water-soluble N reported for dairy cows (25%, Larsen *et al.*, 2001) and sheep (15–24%, Mason, 1969; Mason *et al.*, 1981ab).

Because the proportion of N excreted as undigested feed is slightly higher and the proportion excreted in microbial material is slightly lower than reported in literature, our model might underestimate protein digestion in the LI. The assumptions for LI digestibility resulted in an average apparent N digestion in the LI of 6% of the duodenal outflow (ranging from –1 to 10) which is considerably lower than that found for sheep (21%, Drochner & Meyer, 1991). This lower value may partly be attributed to the lower retention time for digesta in the LI of dairy cows compared to sheep. Expressed in g day^{-1}, apparent N digestion in the LI ranged from –1 to 15. This range is only slightly below that of 5–20 g N day^{-1} derived from Van der Walt (1993) and it is therefore not likely that the net N digestion in the LI has been underestimated significantly.

The percentage of faecal OM excreted with NDF ranged from 43–71% (data not shown) and corresponds reasonably with reported values of 57–61% of faecal OM by Robinson *et al.* (1987), 32–56% of faecal DM by Sørensen *et al.* (2003), and 50–60% of faecal DM by Powell *et al.* (2006). According to Van Soest (1994) the N content of the non-NDF faecal OM is 7%. Our simulated average N content of 8% (data not shown) is in fair agreement with this figure. The simulated non-NDF faecal OM consisted for 9–15% of FEC, 66–75% of FMC and the remainder (14–24%) was FOFC. Hence, microbial matter synthesized in the rumen appeared to contribute most.

Urinary excretion

The simulated proportion of urinary N excreted with urea ranged from 62 to 86% with an average of 78%. These values are in considerable agreement with the range assessed by Whitehead & Raistick (1993) after feeding different diets (67–91%) as well as the range Bussink & Oenema (1998) reported in their review (50–90%) and the average value (71 ± 8.9%) found by Burgos *et al.* (2005) for typical Californian dairy herds. Bussink & Oenema (1998) stated that non-urea-like urinary components (UNUC) are generally excreted in fairly constant amounts. They calculated an average UNUC excretion of 31 ± 4 g N day^{-1}. As our assumptions are partly based on the same data sources, it is no surprise that they result in similar UNUC-N excretions of 27 ± 6 g N day^{-1}. The variation in the simulated UNUC-N (g day^{-1}) excretion is mainly determined by the variation in Hi (5% of total urinary N) and Aa (2% of total urinary N) as the other UNUC constituents were estimated either as a constant value (g day^{-1}) or as very small fractions of total urinary N. However, the constant fraction of 5% Hi in urinary N is debatable as it is has been shown that this percentage can incidentally amount up to 23% (Nehring *et al.*, 1965; Bristow *et al.*, 1992). Such increased urinary Hi fractions would result in an increase of the urinary C:N ratio. According to Nehring *et al.* (1965) excretion of Hi might increase as the fibre content of the diet is higher. This hypothesis is supported by the fact that Hi is mainly a derivative of rumen microbial fermentation of phenolic cinnamic acids (Martin, 1982) which are constituents of plant lignin (Bravo, 1998). However, experimental data to support this hypothesis are lacking.

5.4.3 Simulation of slurry composition

During storage of liquid manure, organic matter is subject to both anaerobic and aerobic bacterial degradation. To predict the composition of the slurry that is actually applied to the field, the digestion model presented in this study was extended with rather simple equations describing these processes. The formulated assumptions resulted in average organic and inorganic N contents (29 and 33 g kg^{-1} OM, respectively; Table 5.7) which corresponded closely to the average values of a large database of Dutch dairy slurries (De Visser *et al.*, 2005, 31 and 32 g kg^{-1} OM, respectively). Also the observed ranges (Table 5.7) showed good correspondence with the ranges observed in practice.

In this study, the proportion of OM degraded during 4 months of storage was estimated at 13% based on Sørensen (1998). This value was obtained at a temperature of 15 °C (Sørensen, 1998). Hindrichsen *et al.* (2006) reported a far higher OM degradation ranging from 32 to 47% within 14 weeks of anaerobic storage after feeding four different diets. This experiment was, however, conducted with an ambient temperature of 24°C. Whitehead & Raistick (1993) showed that slurry OM degradation after 3 weeks of storage, ranged from 14 to 34% and increased with slurry temperature (5–35°C). The lower temperature is close to the average Dutch winter temperature, explaining why the estimated 13% OM degradation, provides a reasonable representation of the average Dutch winter situation.

Based on the observations of Van Duinkerken *et al.* (2003), reflecting typical Dutch conditions, losses of N during the storage period (Table 5.7) were estimated as a fixed percentage of urinary urea-N and ranged from 11–73 g day^{-1} for the 40 nutritional strategies. These results confirm the strong potential to reduce ammonia emission by means of a reduction of the dietary protein content, as observed before (Smits *et al.*, 1995; Paul *et al.*, 1998; Külling *et al.*, 2001). However, actual N losses depend on a number of variables like temperature, air flow, cleaning frequency, urease activity and urine puddle replacement rate (Monteny & Erisman, 1998). Misselbrook *et al.* (2005a) showed, for example, that the actual emission from the stable floor with high protein diets might be inhibited by insufficient urease activity.

The formulated assumptions seem to provide a good representation of the average Dutch storage process but the discussed examples reveal that an accurate simulation of slurry storage processes requires more detailed information on several storage conditions. The model presented in this study can provide a sound basis for this.

5.4.4 Nutritional strategies and the composition of slurry N

The presented model simulates a large variation in slurry N content (Fig 4). This variation intrinsically affects the plant availability of N after field application. Expressed per kg of slurry N, plant availability is related to the $N_{inorganic}$: N_{total} ratio (Sørensen *et al.*, 2003; Chapter 4). This ratio ranged from 0.34 to 0.65 for the 40 nutritional strategies with an average of 0.52 and resulted from a strong variation in slurry inorganic N combined with a moderate variation in the organic N content of slurry (Table 5.7). This simulated variation corresponds closely to the range (0.30–0.60) in $N_{inorganic}$: N_{total} ratio typically observed on commercial dairy farms in the Netherlands (Schröder, personal communication).

Organic N in slurry is mainly derived from faecal material. Due to a large variation in faecal OM excretion (3.1–5.8 kg day^{-1}, Table 5.5) compared to the relatively smaller variation in faecal N excretion (128–177 g day^{-1}, Table 5.5), the simulated faecal N content was positively related to the apparent digestibility of the diet. This is in correspondence with findings of Mason (1969), Kyvsgaard *et al.* (2000) and Sørensen *et al.* (2003). In the present study, low faecal N contents were simulated for diets that contained LC silages, maize silage or 40% of concentrate feeds. In accordance, these nutritional strategies also showed lowest organic N contents in the slurry (Figure 5.5). The variation in simulated slurry organic N content (from 23 to 35 g kg^{-1} OM) was smaller than the variation in faecal N content (from 27 to 49 g kg^{-1} OM) due to the fact that high digestible diets (eg. EC silages) contain also a relatively small NDF fraction implying a higher mineralization of faecal N during storage. Our simulation results reveal only a limited scope for variation in the organic N content of slurry.

The major part of the variation in slurry N content results from the variation in the inorganic N content of slurry (Fig 4). This inorganic N content is determined by the excretion of UUC-N relative to the total OM excretion. Therefore, the highest slurry inorganic N contents are observed when diets are fed that combine a high UUC-N excretion with a high OM digestibility. This combination is highly applicable to the nutritional strategies in this study based on the HFEC silages. The opposite is true for diets based on LFLC grass silage and maize silage: a low excretion of UUC-N coincides with a high OM excretion. As the LFLC diets also contain a high NDF fraction, the simulated mineralization of faecal N during storage was low, resulting in extremely low inorganic N contents and $N_{inorganic}$: N_{total} ratio's.

Sørensen *et al*. (2003) showed that slurry N availability (expressed per kg slurry N) to a barley crop was strongly related to the slurry C:N_{total} ratio. These findings were confirmed on grassland (Chapter 4). This finding may be explained by an immobilizing effect of organic manure components with a high C:N ratio (Van Faassen & Van Dijk, 1987; Chadwick *et al*., 2000; Van Kessel *et al*., 2000). Slurry C:N_{total} ratio is affected by the composition of the diet and reported values range from 7.5 to 10.5 by Paul *et al*. (1998), from 6.4 to 13.1 by Sørensen *et al*. (2003) and from 5.1 to 11.4 (Chapter 4). The simulated range in C:N_{total} ratio (from 4.4 to 11.9) is in line with these results. Following our model simulations, a high C:N_{total} ratio reflects both a high C excretion with FFFC and a low N excretion with UUC. Again, diets that combine a low UUC-N excretion with a low NDF digestion (LFLC, MSIL) show the highest values, whereas lowest values are observed for diets with excessive availability of digestible protein and a highly digestible NDF fraction (HFEC). The other selected strategies did not cause pronounced effects on simulated C:N_{total} ratio (Fig 4). The latter results indicate that for substantial changes in slurry C:N_{total} ratio and the subsequent plant availability of N rather large adjustments in the diet composition are required affecting both UUC-N excretion and FFFC-OM excretion.

5.4.5 The added value of the followed approach

In this study, a dynamic and mechanistic model of rumen fermentation was used to predict the composition of excreta as a function of diet composition. The equations used to predict the composition of faeces and urine seem to provide a correct representation of digestion as the observed ranges in faecal and urinary composition were largely in line with values reported in literature. In particular for the prediction of the digestion in the LI and of the amount of non-urea-like urinary components, additional quantitative information on dietary effects can refine the model.

As this model takes into account interactions between different types of nutrients and the interaction with microbial activity, its use may significantly improve the prediction of feed digestion in comparison to current static feed evaluation systems (Bannink *et al.*, 2007). This feature is clearly illustrated by the prediction of a reduced digestion of rumen digestible fibre on diets that contain a large fraction of concentrate feeds (Fig 3). This prediction is in line with observations of Sørensen *et al.* (2003) who showed that the content of forage-derived decomposable fibre in the slurry was higher when the diet included concentrates. The model is therefore capable of an accurate prediction of the partitioning of N excretion in faeces and urine and contributes to a better understanding of the effect of nutritional strategies on the utilization of N in the cow and the direct losses of N in the slurry storage.

Compared to an earlier integrated model (Kebreab *et al.*, 2004) the model presented in this study predicts not only the amount but also the composition of excreta N. Mineralization, immobilization and plant availability of N from soil-applied dairy manure is affected by the composition of the manure (Chae & Tabatai, 1986; Van Kessel *et al.*, 2000; Chadwick *et al.*, 2000; Powell *et al.*, 2006). These effects are often complex and variable for different crops and soils and therefore the plant availability of N following organic manure application is difficult to predict. Several authors have shown that differences in plant availability of N from soil-applied manure are related to differences in cow nutrition (Kyvsgaard *et al.*, 2000; Sørensen *et al.*, 2003; Powell *et al.*, 2006). The current model helps to understand how differences in manure composition are related to the composition of the diet and therefore it might contribute to a better prediction of plant availability of N following field application of cattle manure.

5.5 Conclusions

The presented extended model seems to provide a correct representation of the complete track of feed digestion in the cow and therefore it is a useful instrument to understand differences in excreta composition related to diet formulation. The simulation results demonstrate the substantial effects of diverging diets on total N excretion and the composition of excreta in terms of immediately available N for plant uptake and the C:N ratio of the resistant N fraction. The model might significantly contribute to a better utilization of N from field applied manure and it can provide essential information for a more elaborate evaluation of the effect of different nutritional strategies at the whole-farm level.

Chapter 6

Re-balancing N in diet and manure on grassland based dairy farms: an empirical study

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Re-balancing N in diet and manure on grassland based dairy farms: an empirical study

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Abstract

The farmers of the environmental co-operatives VEL and VANLA (V&V) in the north of the Netherlands started a nutrient management project in 1998 with the aim to reduce nitrogen surpluses in a cost-effective way. A typical element of this project was the adjustment of the composition of grass silage towards reduced protein and increased fibre contents since silage maize was hardly grown by these farmers. This strategy aimed at a reduction of excessive protein feeding and a shift in the composition of slurry, making it less susceptible to mineral N losses. The current study describes winter diet composition, slurry composition and herd performance on twelve farms of the VEL and VANLA project a few years after the start of the project in compared to the initial situation.

The typical reduction of both the net energy (VEM) and crude protein (CP) level of the grass silages was widely adopted. Compared to the initial situation, the farmers succeeded to reduce the CP:VEM ratio of the grass silage. As a result of this, dietary CP and rumen N balance (OEB) levels decreased substantially. The aimed increase of the slurry $C:N_{total}$ *ratio and reduction of the slurry* $N_{inorganic} : N_{total}$ *ratio were both achieved.*

The diet adjustments proposed by the project were on average associated with higher economic margins per kg milk and a reduced N excretion but slightly lower levels of milk production per cow. Considering the farms in more detail, it appeared that farms that stabilized or decreased feed costs in the course of the project had improved the environmental performance whereas the farms with increased feed costs had not. Thus, on the latter farms the proposed strategy was not successful.

It is concluded that feeding strategies to reduce N excretion should always focus on a decrease of the protein to energy ratio, especially that of the homegrown forage but the definition of the strategy should be individually differentiated.

6.1 Introduction

From the 1960s onwards, the intensification of Dutch agriculture was largely based on the use of increasing amounts of external inputs, especially artificial fertilizers and concentrate feeds. The associated development trajectory has not only resulted in a strong increase in productivity but also in large nutrient surpluses, causing a cascade of negative environmental effects (e.g. Vitousek *et al*., 1997; De Vries *et al*., 2003). Dairy farming has been the primary source of N surpluses in the Netherlands (e.g. Van Bruchem & Tamminga, 1997). Efforts made during the last decades have resulted in a decrease of the N surpluses for specialized Dutch dairy farms from approximately 400 in 1985 to 200 kg N ha^{-1} in 2001 (Hubeek & De Hoop, 2004). However, to comply with future environmental policies (NEC Directive, Waterframework Directive) further improvements have to be made in the minimization of N emissions to the environment.

Agricultural production involves the co-ordination and fine tuning of an extensive range of growth factors or resources (e.g. De Wit *et al*., 1992). With increasing insights, farmers continuously adjust individual resources such as fields, cattle, crops and diets. In this way step-by-step improvements in the production process are created. The introduction of environmental legislation, however, required a rapid and drastic reduction of the input of N with external resources such as inorganic fertilizer and concentrate feeds on dairy farms (Van Bruchem *et al*., 1999a, Aarts, 2000). Reducing these external inputs strongly interferes with this step-by-step fine tuning, provoking an accelerated process. Van der Ploeg *et al*. (2004) referred to this accelerated fine tuning as an integrated downgrading of resources. The nutrient management project of two environmental co-operatives VEL and VANLA (V&V) (Renting & Van der Ploeg, 2001; Stuiver & Wiskerke, 2004) aimed at a reduction of N surpluses through a specified strategy of integrated downgrading. This specific strategy was labeled as the 're-balancing strategy' (Verhoeven *et al*., 2003), referring to the search for a renewed balance in the production process, following the reduction of external nutrient inputs.

Adjustment of diet composition was one of the crucial elements (Chapter 2) of this re-balancing strategy. Several researchers have discussed the importance of cow nutrition in the context of reducing N surpluses from dairy farms. Through dietary adjustments the conversion efficiency of feed N into milk can be substantially improved and the amount of N excreted in faeces and urine can be significantly reduced by lowering the dietary protein content (Castillo *et al*., 2000; Kebreab *et al*., 2002; Børsting *et al*., 2003). Moreover, nutrition not only affects the utilization and excretion of N by the cow, but also the composition of excreta and therefore it interacts with the major part of the processes at farm level where N is converted and lost. Utilization of N from soil-applied slurry (e.g. Paul *et al*., 1998; Sørensen *et al*., 2003; Chapter 4) as well as N losses from slurry storage (Smits *et al*., 1995; Paul *et al*., 1998; Külling *et al*., 2001) have been shown to be affected by cow nutrition.

In the V&V nutrient management project, diet adjustments were promoted with the objective to increase feed N conversion efficiency and to reduce N losses throughout the farming system by a change in the composition of slurry. It was anticipated that these goals could be achieved simultaneously through decreased protein contents and increased fibre contents of the diets, established through a shift in grass silage composition. Verhoeven *et al.* (2003) hypothesized that these adjustments would not hamper the economic performance as they were embedded in an integrated re-balancing strategy. In this study, twelve farms of the V&V project were extensively monitored for three consecutive winter season periods a few years after the re-balancing strategy was introduced on these farms to obtain empirical information on diet composition, manure composition, herd performance and their interrelations. Specific objectives were 1) to report if the farmers have adopted the proposed diet adjustments; 2) to get insight in the relation between the proposed diet adjustments and productive, environmental and economic herd performance; 3) to get insight in the relation between the proposed diet adjustments and slurry composition, and 4) to evaluate the effectiveness of the specified re-balancing strategy.

6.2 Material & Methods

6.2.1 Description of the nutrient management project

Vereniging Eastermar's Lânsdouwe (VEL) and Vereniging Agrarisch Natuur en Landschapsbeheer Achtkarspelen (VANLA) are two environmental co-operatives located in the Friesian Woodlands. This region is largely dominated by sandy soils, but also clay and peaty soils can be found. Furthermore it is characterized by a man-made landscape and dominated by small parcels (on average 2 ha) surrounded by hedgerows. The governments' program on nature landscape declared that these hedgerows were sensitive to acid rain. This designation implied substantial restrictions on animal husbandry in the immediate surroundings and was seen by farmers as a threat to future development of their farms. The farmers started negotiating with the government and committed themselves to a more active nutrient management in exchange for a policy decision that the hedgerows were not designated as acid-sensitive (Stuiver & Wiskerke, 2004). As a consequence they were, in 1992, among the first farmers in the Netherlands to document the inputs and outputs of nutrients on their farms and in 1998 the V&V Nutrient Management Project (NMP) was initiated (Stuiver & Wiskerke, 2004).

The NMP consisted of approximately 60 dairy farms with an average size of 50 ha of which the major part is occupied by rarely renovated grassland and only a small proportion (5%) is used for the cultivation of maize. The main goal of this NMP was to find cost-effective strategies to reduce nutrient surpluses by developing practices appropriate to the local context (Stuiver & Wiskerke, 2004). To obtain this goal, a coherent set of management adjustments was formulated based on the practices and ideas of local farmers who showed already low N surpluses before the start of the project, and these were enriched and strengthened by the concepts presented by Van Bruchem *et al*. (1999a). This set of management adjustments was presented as the V&V re-balancing strategy.

During the period 1998–2003, this re-balancing strategy was actively promoted in the area. The farmers were encouraged to apply the re-balancing strategy to their specific situation. Complying with the targets for nutrient surpluses in 2003 set by the MINAS system (Henkens & Van Keulen, 2001) was at the same time a goal and a boundary condition for the farmers in the project. Monitoring of relevant farm data and knowledge exchange were important pillars of the project. To stimulate the learning processes (Stuiver *et al*., 2004) the project provided several platforms such as group meetings, excursions, magazines and a website where hypotheses and outcomes were discussed. Furthermore, the project functioned as a field laboratory (Stuiver *et al*., 2003) for various types of scientific research.

6.2.2 Description of the re-balancing strategy

The promoted re-balancing strategy consisted of a set of interrelated management adjustments. Most important adjustment advocated was a strong reduction of the artificial fertilizer input. Furthermore, it was recommended to postpone the cutting moment for grass silage. It was anticipated that the combination of these measures would lead to a decrease in the protein and an increase in the fibre content of the grass silage (Van Bruchem *et al*., 1999b) that was considered as a crucial element in the transition towards diets with a low protein and high fibre content. In the first year of the project largest attention was given to the reduction of artificial fertilizer input and grassland management. From the second year of the project onwards (autumn 1999) the project focused also on the proposed changes in diet composition.

Diets low in protein (resulting in a decreased excretion of N) and high in fibre (resulting in an increased excretion of C) were expected to increase the $C:N_{total}$ ratio of the produced slurry. In line with observations of Paul *et al*. (1998) it was anticipated that these dietary changes would result in lower inorganic N contents and a larger proportion of organically bound N, making the slurry N less susceptible to losses through volatilization and leaching. Van Bruchem *et al*. (1999b) hypothesized that this change in manure composition would contribute to an increased mineralization of soil N in the long term. Furthermore, these diets were also expected to increase the conversion efficiency of feed N into milk and to have a beneficial effect on animal health by a stimulation of rumen functioning and hindgut fermentation (Van Bruchem *et al*., 1999b). The reduced CP content of the ration could potentially (but only at high initial levels of dietary protein) improve animal fertility (Laven & Drew, 1999; Tamminga, 2006). A more healthy and fertile animal stock would reduce costs for cow replacement and veterinary care. With a reduction of the cow replacement rate, slight reductions in individual animal production were considered to be acceptable as the production per ha could subsequently be stabilized by a decrease of the number of heifers in the milking herd and thus a small increase in the ratio milking cows : young stock. In theory, the whole package of measures proposed within the NMP (the re-balancing strategy) should reduce costs (Renting & Van der Ploeg, 2001) by lowering inputs of fertilizers and concentrates and reduced costs for grassland management, cow replacement and veterinary care.

6.2.3 Proposed diet adjustments

Due to the relatively low intensity, most of the farms in the area are self-sufficient in forage production. This implies that fresh grass and grass products are the main diet ingredients. In summer, the typical diet consists largely of fresh grass and in winter first cut grass silage is usually the main component of the diet. However, a large variation exists between these farmers on how this typical strategy is implemented. The access to fresh grass in summer is arranged through stall-feeding, restricted grazing or unrestricted grazing during a variable period of the year, a variable period of the day and variable groups of animals. Both in summer and winter the grass (silage) is replenished with variable amounts and types of concentrates, industrial by-products and maize silage. Maize silage is used on a large scale in grass-based systems in the Netherlands as a means to decrease the dietary protein : energy ratio (CP : VEM ratio), having a strong potential to increase feed N conversion (e.g. Valk, 1994). However, most farmers in the V&V region have limited the production of silage maize as the permanent grasslands play a crucial role in the valuable landscape of the area and they are concerned that the production of maize may have a long term adverse impact on soil characteristics (Sonneveld *et al.*, 2002).

To obtain the desired diets (low in protein and high in fibre) farmers were encouraged to change the composition of the diets towards the guidelines summarized in Table 6.1 (Chapter 2). As most of the farms were self-sufficient in roughage production, it was promoted to maximize the use of homegrown forage and limit the use of concentrate feeds. To increase feed N conversion without a large scale use of maize silage, the NMP focused on a decrease of the CP : VEM ratio of the grass silage (Table 6.1) by means of a reduction of fertilizer application and a delay of the cutting moment. It was anticipated that the reduction of the CP content would be relatively larger than the reduction in energy (VEM) content following the combination of these two measures.

Table 6.1 *Proposed diet adjustments (Chapter 2) in the re-balancing strategy aiming at 1) an increase of the conversion efficiency of feed N into milk, 2) a reduction of the total excretion of N, 3) a reduction in the $N_{inorganic}$: N_{total} ratio of slurry and 4) an increase of the slurry C:N_{total} ratio*

	Characteristic to downgrade	*Guideline*
Whole diet	↓ Crude Protein (CP)	≤ 150 g kg^{-1} DM
	↓ Degraded Protein Balance (OEB)	≤ 0 g cow^{-1} day^{-1}
	↓ Intake of true protein digested in SI[a] (DVE)	100% of requirement[b]
	↓ Net Energy for lactation (VEM)	≤ 900 kg^{-1} DM
	↓ Use of concentrates and other imported feeds	≤ 25 kg 100 kg^{-1} FPCM or ≤ 30% of DM
	↓ CP : VEM ratio	No numerical guideline
Grass silage	↓ Crude Protein (CP, in g kg^{-1} DM)	No numerical guideline
	↓ Digestibility of OM[c] (%)	No numerical guideline
	↓ CP : VEM ratio	No numerical guideline

a) SI = small intestine

b) Requirement for milk production and maintenance, according to Tamminga et al., 1994

c) We use the digestibility of OM here as an indication of fibre as it was the most likely reliable and available parameter related to the amount of C excreted in the slurry

As the fibre content (NDF) of different feedstuffs was still difficult to interpret and for a number of feedstuffs no reliable data on the fibre content were available, it was anticipated that silages with a low digestibility and a low energy content (VEM), also contain larger fractions of fibre (Valk *et al.*, 2000). Therefore, the energy content (VEM) of diets and grass silages, and the organic matter (OM) digestibility of grass silages were used as indicators for the dietary fibre content. Increasing the starch and sugar content of concentrate feeds should guarantee sufficient amounts of energy to maintain animal production levels.

6.2.4 Data collection

From the V&V project, twelve farms were selected to study diet adjustment more elaborately. The enthusiasm and willingness of farmers to co-operate and practical considerations with respect to the weighing of feed to enable feed intake determination were decisive in the selection of the farms. On the selected farms, winter diet composition was registered 9 times between November 2001 until February 2004. For every moment, both the total supply of feed to the milking herd and feed refusals were weighed and registered on-farm during a period of 3 to 7 days. Feed analyses of the forages were derived from the regular feed analyses carried out by commercial firms under authority of the farmer. Feed analyses of concentrate feeds and other imported feeds were derived from the supplier. Data on milk production and composition during the concerned period were supplied by the milk factories, based on standardized measurements. Prices of the imported feeds were supplied by the farmers. During a farm visit, diet composition, herd performance, diet adjustments and the underlying motivations were discussed thoroughly and reported. In the second and third year, faecal samples were taken from 15% of the cows equally divided over different age classes and lactation stages. These faecal samples were pooled and analyzed for dry matter (ISO 6496) and total-N (Kjeldahl method, ISO 5983). Ash was determined in a furnace at 550 °C and total C was determined by elemental analysis using an EA 1110 CHN analyser (CE instruments, Milan, Italy). On every farm, a well mixed sample of slurry manure was taken from the slurry pit twice per winter period (from December to March) to measure organic matter, and organic and inorganic N contents using standardized laboratory methods on commercial labs.

6.2.5 Data analysis

All data were analyzed at the level of the average cow of the herd. Average bodyweight was estimated at 625 kg. Fat and protein corrected milk (FPCM) production was calculated according to:

$$FPCM\ (kg\ cow^{-1}\ day^{-1}) = (0.337 + 0.116 * milk\ fat\ (\%) + 0.06 * milk\ protein\ (\%)) * milk\ production\ (kg\ cow^{-1}\ day^{-1})\ (Anon.,\ 2005a) \tag{6.1}$$

Net energy requirements (VEM_{req}, in VEM cow^{-1} day^{-1}; 1000 VEM = 6.9 MJ) for maintenance and milk production were estimated according to (Anon., 2005a):

$$VEM_{req} = 5163 + 440 * FPCM + 0.73 * (FPCM)^2 \tag{6.2}$$

Extra energy requirements for growth, mobilization and gestation of the herd were estimated to be 400 VEM cow^{-1} day^{-1}. VEM balance (supply as a percentage of requirement) was calculated according to:

$$VEM\ balance\ (\%) = total\ VEM\ intake / (VEM_{req} + 400) * 100\% \tag{6.3}$$

DVE requirements for maintenance and milk production in g cow^{-1} day^{-1} were calculated according to Tamminga *et al*. (1994).

$$DVE_{req} = 117 + 1.396 * milk\ protein\ (g\ cow^{-1}\ day^{-1}) + 0.000195 * milk\ protein^2\ (g\ cow^{-1}\ day^{-1}) \tag{6.4}$$

DVE requirements for growth, gestation and mobilization of the herd were estimated to be 35 g cow^{-1} day^{-1}. DVE balance (DVE supply as a % of DVE requirement) was calculated as:

$$\text{DVE balance (\%)} = \text{total DVE intake} / (DVE_{req} + 35) * 100\% \qquad (6.5)$$

Crude protein contents (CP in g kg^{-1} DM) of the forages were only available exclusive the ammonium N. To account for the ingested ammonium N, the ammonium fraction of all silages was set at 7% of the total N to calculate total N intake.

N retention in body tissue was estimated at a fixed value of 4 gram per cow^{-1} day^{-1} based on average growth and replacement rates in Dutch dairy herds (Tamminga *et al.*, 2004). N in milk production and N excretion were calculated according to:

$$\text{N in milk } (g\ cow^{-1}\ day^{-1}) = \text{milk protein } (g\ cow^{-1}\ day^{-1}) / 6.38 \qquad (6.6)$$

$$\text{N excretion } (g\ cow^{-1}\ day^{-1}) = \text{total N intake} - \text{N in milk} - \text{N retention} \qquad (6.7)$$

Average returns in the monitored period for fat and protein were 3.556 € kg^{-1} and 5.434 € kg^{-1} (Anon., 2005b) and these values were used to calculate standardized milk returns.

Data on diet composition at the start of the project (initial situation in Table 6.8) and general characteristics (Table 6.2) of the same farms were taken from the central database of the V&V project (described in Groot *et al.*, 2006). These data were processed using the same procedure as described above. However, feed prices of individual feedstuffs were not available in this database.

All statistical analyses were performed using SPSS (Anon., 2001). Since not all data were normally distributed, correlation analyses were performed using the nonparametric method of Spearman. Regression analysis between dietary characteristics and N excretion (g kg^{-1} FPCM) were performed using the stepwise linear regression method. Differences in dietary characteristics and herd performance between groups of farms were tested using an independent sample's T-test.

6.2.6 Characteristics of the selected farms

The selected farms had a large variation in farm size and characteristics (Table 6.2). During the course of the project, all farms increased their acreage. The average farm size increased from 49 to 58 ha. The average percentage of land used for maize cultivation decreased from 8% to 5%. At the end of the project there were only 2 farmers that had maize on more than 5% of their land. Total milk production (322–826 Mg at the start of the project) increased on all farms except for farm 4. The average intensity remained stable at 11.7 Mg FPCM ha^{-1}. However, there were two farms that intensified strongly (2 and 7), four farms that showed a small intensification (1, 3, 9, 12) and six farms (4, 5, 6, 8, 10, 11) that reduced the production per ha. The average production level per cow decreased slightly in the course of the project from 8.0 to 7.8 Mg FPCM cow^{-1} year^{-1}.

On average, the import of feed N increased slightly in the course of the project (from 99 to 103 kg N ha^{-1}) but there was a great variation between the farms (Table 6.2). Five farms showed a decrease whereas feed N imports increased on the other seven farms. The import of fertilizer N was reduced on all farms in the course of the project and this reduction was on average 106 kg N ha^{-1}. In the final year of the project, the use of fertilizer N was restricted to 124 kg N ha^{-1}, ranging from 66–166 kg N ha^{-1} (Table 6.2). This strong reduction in the use of fertilizer N resulted in the aimed reduction of the farm gate N surpluses. With exception of farm 2, all farms complied with the 2003 targets of the MINAS legislation (Henkens & Van Keulen, 2001) at the end of the project (180 kg N per ha^{-1} for grassland) and most of them decreased the surplus even below this level.

Though the farms in the present study operate in the same region and share common objectives through participating in the NMP, the proposed changes in diet composition (Table 6.1) did not result in homogeneous outcomes. Main objective of the farmers in the NMP was to develop cost-effective strategies to reduce the environmental impact of their farms (Stuiver & Wiskerke, 2004). However, total costs for imported feeds (per kg FPCM) showed a large variation between the farms and this variation was only slightly related to the intensity of the farms. To evaluate the success of the feed adjustments in terms of cost-effectiveness, the twelve farms have been divided into two groups based on the development of yearly feed costs in the course of the project (Table 6.2). Farms 1, 4, 6, 7, 8, 9 and 11 showed stabilized or decreased feed costs per kg FPCM at the end of the project as was the anticipated outcome of applying the re-balancing strategy (Verhoeven *et al.*, 2003; Chapter 2). On these farms, the diet adjustments have been successful in terms of economic performance and these farms were denominated as group S (stabilized feed costs). On the other farms (2, 3, 5, 10 and 12) feed costs increased in the course of the project and the adjustments these farmers have made, appear less successful in terms of economic performance. This group is denominated as group I (increased feed costs).

Table 6.2 *Farm characteristics of the selected farms before the start (1997/1998) and at the end (2002/2003) of the project.*

Farm number		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Mean*
Milk production	Start	322	789	541	665	395	370	506	826	369	767	623	657	569
(Mg FPCM year^{-1})	End	401	1009	622	644	544	410	658	882	414	888	838	780	674
Acreage	Start	39	72	49	69	34	35	39	61	35	52	47	56	49
(hectares)	End	40	76	53	71	49	49	41	90	36	61	67	61	58
Maize cultivation	Start	12	6	0	0	0	0	0	13	15	38	7	6	8
(% of ha)	End	3	0	0	0	16	0	0	4	0	28	5	2	5
Intensity	Start	8.3	11.0	11.0	9.6	11.5	10.6	12.9	13.5	10.7	14.7	13.3	11.7	11.6
(Mg FPCM ha^{-1})	End	10.0	13.3	11.7	9.1	11.2	8.4	16.1	9.8	11.4	14.6	12.6	12.7	11.7
Production level	Start	8.3	8.5	8.9	6.6	7.2	7.6	n.a.	8.4	8.0	8.7	7.7	7.8	8.0
(Mg FPCM cow^{-1})	End	7.6	8.2	8.4	5.9	7.6	7.6	n.a.	7.8	8.3	8.3	8.1	8.4	7.8
Feed N import	Start	39	110	86	57	78	93	128	108	78	172	118	122	99
(kg N ha^{-1})	End	87	129	76	62	96	64	131	93	114	183	93	109	103
Fertilizer N import	Start	159	197	249	191	250	284	246	295	165	183	274	261	230
(kg N ha^{-1})	End	149	135	152	121	144	83	166	124	66	80	125	137	124
Feed costs[b]	Start	5.3	5.2	6.1	5.3	4.5	5.5	6.4	6.1	6.4	7.0	6.5	6.0	5.9
(€ 100 kg^{-1}FPCM)	End	4.8	6.8	8.5	5.6	6.7	4.1	4.2	6.0	6.7	8.5	5.8	8.1	6.5
Development of feed costs	GROUP[c]	S	I	I	S	I	S	S	S	S	I	S	I	

a) The data in this table are obtained from the central database of the nutrient management project

b) Total costs for all imported feeds

c) Based on the development of feed costs between the start and the end of the project. Two groups are distinghuished. Farms where feed costs stabilised or decreased during the course of the project (S) and farms where feed costs increased (I).

6.3 Results & Discussion

6.3.1 Adoption of the proposed diet adjustments

The observed diet composition in the monitored period (2001–2004) has been summarized in Table 6.3 and compared with the initial situation (1998/1999) on the same farms as well as with the averages obtained in the “Cows and Opportunities”-project (C&O) in winter 2001–2003 (Šebek & Oenema, personal communication). In the latter project, 17 farms were selected representing the full range of conditions for dairy farming in the Netherlands, with emphasis on dry sandy soils. These farms function as national pilot farms where nutrient management strategies are implemented and their effects extensively monitored, evaluated and discussed. In this project a change of the feeding regime has also been identified as one of the important nutrient management strategies (Oenema *et al.*, 2001) and therefore the results of this project can be used as a relevant reference.

The average CP content of the diet decreased from 173 g kg^{-1} DM in the initial situation to 159 g kg^{-1} DM in the monitored period. The average OEB has been reduced strongly (from 529 to 234 g cow^{-1} day^{-1}) compared to the initial situation but the average supply of DVE remained high at 113% of the requirements for milk production. Both OEB and DVE supply showed an enormous variation between farms as well as in time at a given farm. The average CP content, OEB value and DVE supply show great similarity with the average values reported for the C&O project (157 g kg^{-1} DM, 265 g cow^{-1} day^{-1} and 111%, Table 6.3) and also in this project large variation between farms was observed (Šebek & Oenema, personal communication). For both protein characteristics, the average values exceeded the optimum values of the protein evaluation system (Tamminga *et al.*, 1994) which were used as guidelines (Table 6.1).

The average DM intake of 19.8 kg DM cow^{-1} day^{-1} (ranging from 15.7 to 24.5 kg cow^{-1} day^{-1}) was slightly higher than observed at the start of the project but corresponded closely to the value of 19.9 kg DM cow^{-1} day^{-1} observed in the C&O project. The use of concentrates in the monitored period showed considerable variation. It ranged between 19 and 54% of total DM intake, corresponding to 15–39 kg 100 kg^{-1} FPCM. However, the average in the monitored period (34%, 26 kg 100 kg^{-1} FPCM) was not reduced compared to the initial situation (35%, 25 kg 100 kg^{-1} FPCM) and also higher than the average concentrate use observed in the C&O-project (30%, 23 kg 100 kg^{-1} FPCM). Despite this higher concentrate use for the monitored farms compared to the C&O farms, the average energy content (VEM) of the diet was considerably lower (Table 6.3), due to the lower energy content of the forage. Compared to the start of the project, the average energy content of the diet was slightly reduced (from 952 to 938 VEM kg^{-1} DM, Table 6.3).

Table 6.3 *Mean, minimum (Min.) and maximum (Max.) of dietary characteristics of twelve farms of environmental co-operatives VEL and VANLA (V&V) in three winter periods (2001–2004) relative to the initial situation (98/99) on these farms and to the results of the project Cow and Opportunities (C&O) in winter 2001–2003 (Šebek & Oenema, personal communication)*

Dietary characteristics		*V&V 98/99*	*V&V 2001–2004*			*C&O 2001–2003*
		Mean	Mean	Min.	Max.	Mean
Dietary characteristics proposed to downgrade	*Whole diet*					
	CP (g kg^{-1} DM)[a]	173	159	133	184	157
	OEB (g cow^{-1} day^{-1})	529	234	–463	714	265
	DVE (% of requirement)	112	113	84	140	111
	VEM (kg^{-1} DM)	952	938	846	1016	960
	Concentrates (% of DM)	35	34	19	54	30
	Concentrates (kg 100 kg^{-1} FPCM)	25	26	15	39	23
	CP:VEM ratio	0.182	0.170	0.143	0.196	0.164
	Grass silage					
	CP (g kg^{-1} DM)[b]	173	146	112	171	166
	DC_{OM} (%)	n.a.	74.3	67.3	78.9	n.a.
	CP:VEM ratio[b]	0.196	0.172	0.134	0.208	0.187
Additional dietary information	DMI (kg DM cow^{-1} day^{-1})	19.6	19.8	15.7	24.5	19.9
	N intake (g cow^{-1} day^{-1})	544	505	374	656	501
	Maize silage (% of forage DM)	n.a.	12	0	53	41
	VEM of grass silage (kg^{-1} DM)	880	849	744	923	886
	VEM (% of requirement)	108	109	91	139	107

*a) Including ammonium fraction of grass silages, calculated as (N intake * 6.25) / DMI.*
b) Ammonium fraction not included

The high use of maize silage in the Netherlands is reflected in the C&O project, where 41% of the forage DM consists of maize silage (Table 6.3). On the monitored farms in the V&V project on average only 12% of the forage DM consisted of maize silage and in 65% of the cases maize silage was absent in the diet, indicating that the strategy of limiting the use of maize silage was indeed adopted on a large scale. As a result of this minimal use of maize silage, the CP : VEM ratio of the diet had to be reduced otherwise to improve feed N conversion. Compared to the initial situation, the average CP : VEM ratio of grass silage indeed decreased (from 0.196 to 0.172, Table 6.3), due to a greater reduction in CP than in VEM. Both, VEM and CP of the grass silages in the monitored period were considerably lower than observed in the C&O project and also the CP : VEM ratio was considerably lower on the V&V farms (Table

6.3). Remarkable are the extremely low minimum values of 744 VEM kg^{-1} DM and 112 g CP kg^{-1} DM and the absence of grass silages with more than 171 g CP kg^{-1} DM on the monitored farms (Table 6.3). These values indicate that the strategy of adjusting the grass silage composition (Table 6.1) has been widely adopted in the project.

Table 6.4 shows that high dietary CP contents were significantly associated with a higher use of concentrates, a higher dietary energy level (VEM) and grass silages with a higher OM digestibility. Furthermore, the CP content of the grass silage was significantly and positively correlated with the energy level of the whole diet and the OM digestibility of the grass silage (Table 6.4). These positive correlations reveal on the one hand that the measures presented in Table 6.1 form a coherent set, as was anticipated (Chapter 2). On the other hand, these correlations clearly illustrate that relations between dietary characteristics and herd performance can not be interpreted as the single effect of changing one dietary characteristic.

Table 6.4 *Standardized correlation coefficients[a] (Spearman's rho) between protein- and energy-related diet characteristics (N=108)*

Protein-related diet characteristic	*Energy-related diet characteristic* Concentrates (% of dietary DM)	Whole diet VEM (kg^{-1} DM)	OM digestibility (%) of grass silage
Whole diet			
CP (g kg^{-1} DM)	+0.25**	+0.31**	+0.21*
OEB (g cow^{-1} day^{-1})	+0.09	+0.17	+0.11
DVE supply (% of requirement)	+0.08	+0.03	+0.19
Grass silage			
CP (g kg^{-1} DM)	+0.13	+0.36***	+0.36***

*a) Statistically significant (n = 108) * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$*

6.3.2 Herd performance in relation to diet composition

Average milk production per cow decreased slightly in the monitored period compared to the initial situation (from 25.2 to 24.5 kg cow^{-1} day^{-1}), but with a distinct increase of the fat content (from 4.44 to 4.55%) and a marginal increase of the protein content (from 3.47 to 3.48%, Table 6.5). These changes resulted in only a small decrease of the FPCM (from 26.5 to 26.1 kg cow^{-1} day^{-1}) and milk N production (from 137 to 133 g cow^{-1} day^{-1}) compared to the initial situation. Average production, both in terms of FPCM and milk N, was slightly lower on the monitored farms than those of the C&O project (Table 6.5).

Table 6.5 *Mean, minimum (Min.) and maximum (Max.) of herd performance on twelve farms of the VEL & VANLA project (V&V) in three winter periods (2001–2004) relative to the initial situation (98/99) on these farms and to the results of the project Cow and Opportunities (C&O) in winter 2001–2003 (Šebek & Oenema, personal communication)*

Herd performance		V&V 98/99	V&V 2001–2004			C&O 2001–2003
		Mean	Mean	Min.	Max.	Mean
Productive	Milk (kg cow^{-1} day^{-1})	25.2	24.5	17.1	31.3	24.7
	- fat (% of milk)	4.44	4.55	3.92	5.05	4.58
	- protein (% of milk)	3.47	3.48	3.17	3.79	3.51
	- lactose (% of milk)	4.51	4.51	4.41	4.64	4.51
	- urea (mg dl^{-1})	23.2	21.4	13	32	21.5
	FPCM (kg cow^{-1} day^{-1})	26.6	26.1	18.9	31.8	26.6
	Milk N (g cow^{-1} day^{-1})	137	133	99	160	136
Economic	Margin[a] (€ 100 kg^{-1}FPCM)	n.a.	28.1	24.6	31.4	n.a.
	Margin[a] (€ cow^{-1} day^{-1})	n.a.	7.3	5.5	8.8	n.a.
Environmental	N excretion[b] (g cow^{-1} day^{-1})	403	368	250	503	365
	N excretion[b] (g kg^{-1} FPCM)	15.3	14.2	9.8	18.9	13.8
	N efficiency[c] (%)	25.2	26.5	21.2	34.0	27.3

a) Calculated as milk returns minus costs for imported feeds
b) Calculated as N ingested with feed minus N in milk minus N retention
*c) Calculated as (N in milk / N ingested with feed) * 100%*

Table 6.6 reveals that several of the parameters that were proposed to downgrade in the NMP (whole diet VEM, CP and OEB and the percentage of concentrates, Table 6.1) were positively correlated to the level of milk production (kg FPCM cow^{-1}). This implies that the proposed downgraded diets are associated with a lower level of milk production: cows that received diets with lower levels of energy and protein produced less milk or the other way around: cows that produced more milk received diets with higher levels of energy and protein.

The margin between standardized milk returns and costs for imported feeds ranged from 24.6 to 31.4 € 100 kg^{-1} FPCM and from 5.5 to 8.8 € cow^{-1} over the three years (Table 6.5). Such differences can have a large impact on gross margin (Ondersteijn *et al.*, 2003a). Unfortunately, reference data for the initial period and the C&O project were not available. Feed margin (€ 100 kg^{-1} FPCM) showed a significant negative correlation with several of the diet characteristics proposed to downgrade (DVE supply, CP, OEB and the CP:VEM ratio of the whole diet; Table 6.6), implying that farmers that made use of the proposed downgraded low protein diets (Table 6.1) achieved higher feed margins than farmers that did not.

Average N excretion was reduced in the course of the project, both per cow and per kg FPCM (Table 6.5). N efficiency ranged from 21 to 34% in the monitored period and the average increased only slightly compared to the initial situation (26.5% versus 25.2%, Table 6.5). The average environmental herd performance observed in the C&O project was of a similar magnitude but slightly better for all indicators (Table 6.5). N excretion per cow was positively correlated with most of the dietary characteristics proposed to downgrade (Table 6.6), indicating that applying the proposed strategy can be clearly associated with a reduction of the N excretion per cow. The strong correlation between CP, OEB, DVE supply and CP : VEM ratio's on the one hand and N excretion per kg FPCM and the N efficiency on the other (Table 6.6) show the strong possibilities to increase feed N conversion by lowering the protein content of the feed as demonstrated before (e.g. Castillo *et al.*, 2001; Kebreab *et al.*, 2002; Broderick, 2003).

Table 6.6 *Standardized correlation coefficients[a] (Spearman's rho) between dietary characteristics and herd performance (N=108)*

Dietary characteristic	*Herd performance* FPCM (kg cow^{-1} day^{-1})	Feed margin (€ 100 kg^{-1} FPCM)	N excretion (g cow^{-1} day^{-1})	N excretion (g kg^{-1} FPCM)
Whole diet				
CP (g kg^{-1} DM)	+0.25 **	–0.44 ***	+0.67 ***	+0.62 ***
OEB (g cow^{-1} day^{-1})	+0.20 *	–0.41 ***	+0.60 ***	+0.56 ***
DVE supply (% of requirement)	–0.15	–0.20 *	+0.56 ***	+0.78 ***
VEM (kg^{-1} DM)	+0.47 ***	–0.30 **	+0.23 *	–0.08
Concentrates (% of DM)	+0.32 **	–0.49 ***	+0.15	–0.10
CP:VEM ratio	+0.08	–0.30 **	+0.61 ***	+0.68 ***
Grass silage				
CP (g kg^{-1} DM)	+0.04	–0.08	+0.39 ***	+0.44 ***
OM digestibility (%)	+0.14	+0.06	+0.19	+0.13
CP:VEM ratio	–0.05	–0.12	+0.37 ***	+0.47 ***

*a) Statistically significant (n = 108) * = P < 0.05; ** = P < 0.01; *** = P < 0.001*

In spite of the fact that energy and protein-related characteristics were internally positive correlated (Table 6.4), energy-related characteristics (whole diet VEM, % of concentrates and OM digestibility of the grass silage) were not associated with a decrease of the N excretion per kg FPCM (Table 6.6). This observation clearly illustrates that reducing the energy content of diets did not contribute to an increase of the feed N conversion in itself. Moreover, model predictions of Kebreab *et al.* (2002) and an experiment of Broderick (2003) showed that feed N efficiency increased with increasing dietary energy contents. Also Hojman *et al.* (2004) reported, after analysis of data from a large number of Israeli dairy herds, a negative association between the dietary energy content and milk urea, indicating a positive relation between dietary energy and feed N efficiency. From these data we conclude that a decrease in the energy content of diets as advocated in the NMP can only improve feed N conversion when it is associated with a relatively larger decrease of the dietary CP content, resulting in a decrease of the CP : VEM ratio.

6.3.3 Slurry composition in relation to diet composition

With respect to slurry composition, the aims of the diet adjustments proposed in the V&V project were to decrease the ratio between inorganic and total N and to increase the slurry C:N_{total} ratio. In line with these targets, the $N_{inorganic}$: N_{total} ratio of the produced slurry decreased from 55% in 1999 to an average of 45% in the monitored period (Figure 6.1) and the average C:N_{total} ratio increased from approximately 7 (not shown) to 8.9 (Table 6.7).

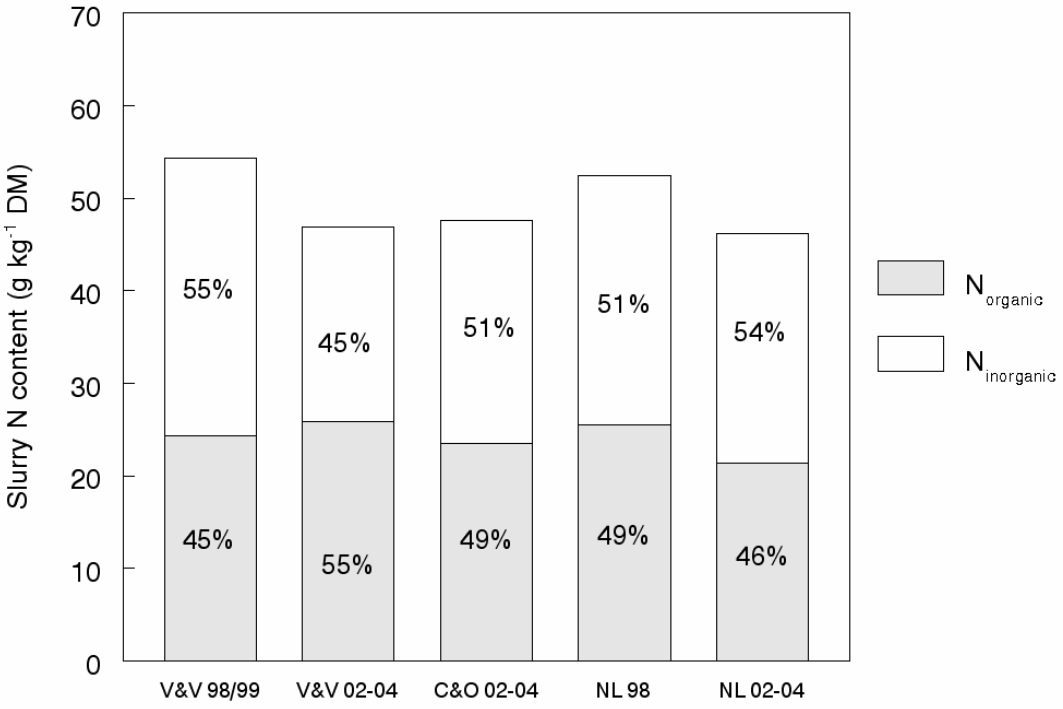


Figure 6.1 *Slurry N content on the selected farms in the initial situation (V&V 98/99) and in the monitored period (V&V 02–04) in comparison with the C&O project (C&O 02–04, Oenema, personal communication) and national reference values (NL 98, NL 02–04, Reijneveld, personal communication)*

Table 6.7 *Mean, minimum and maximum values of slurry composition (n=36) on 12 VEL and VANLA farms in the period 2001–2004 and correlation coefficients*[a] *(Spearman's rho) between slurry characteristics and dietary characteristics (N=36)*

	Slurry characteristics				
	DM (g kg^{-1})	*$N_{organic}$ (g kg^{-1}DM)*	*$N_{inorganic}$ (g kg^{-1}DM)*	*N_{inorg} :N_{total} ratio*	*C : N_{total} Ratio*[b]
Mean	93	26	21	0.45	8.9
Range (min–max)	68–120	22–31	13–28	0.34–0.54	7.3–11.8
Dietary characteristics	*Correlation coefficients*				
Whole diet					
CP (g kg^{-1} DM)	–0.17	–0.14	+0.31	+0.33 *	–0.33 *
OEB (g cow^{-1} day^{-1})	–0.39 *	–0.19	+0.40 *	+0.41 *	–0.39 *
DVE supply (% of requirement)	–0.01	–0.27	+0.05	+0.18	+0.05
VEM (kg^{-1} DM)	–0.08	–0.27	+0.38 *	+0.47 **	–0.20
Concentrates (% of DM)	–0.20	+0.11	+0.36 *	+0.28	–0.37 *
CP:VEM ratio	–0.18	–0.12	+0.27	+0.28	–0.32
Grass silage					
CP (g kg^{-1} DM)	–0.29	–0.26	+0.36 *	+0.43 **	–0.22
OM digestibility (%)	–0.26	–0.36 *	+0.28	+0.45 **	–0.12
CP:VEM ratio	–0.27	–0.23	+0.26	+0.33	–0.17

*a) Statistically significant (n = 36). * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$*
*b) Assuming a C content of 0.55 * OM, being the mean value observed in Chapter 4)*

Before evaluating the correlation coefficients between slurry and diet characteristics (Table 6.7), it needs to be stressed that the sample size was very limited and that the variation in slurry composition could have been influenced by differences in other factors than diet composition such as bedding material, storage time and conditions, the addition of cleaning water or the use of additives. Nevertheless, the results are interesting as they provide valuable information on the possible mechanisms behind the observed changes in slurry composition.National reference values show a substantial reduction in the slurry N_{total} content during the period between 1998 and the monitored period (2002–2004) (Figure 6.1), probably as the result of the introduction of MINAS and milk urea monitoring by dairy factories that have stimulated the reduction of excessive protein feeding in that period. On the 12 farms in the current study, the reduction of the slurry N_{total} content compared to the initial situation was of a similar magnitude (Figure 6.1). However, the composition of slurry N differed markedly on the V&V farms. Whereas the reduction of slurry N_{total} content in the C&O project and national reference values was reflected in lower contents of both $N_{organic}$ and $N_{inorganic}$, the V&V farms showed a strong reduction of the slurry $N_{inorganic}$ content accompanied by a small increase in the $N_{organic}$ content (Figure 6.1). This resulted in the aimed reduction of the $N_{inorganic}$: N_{total} ratio. Several of the dietary characteristics proposed to downgrade in the current project appeared to be correlated with a lower $N_{inorganic}$: N_{total} ratio in the slurry (Table 6.7), indicating that the typical diet adjustments proposed by the V&V project have played a crucial role in this reduction.

$N_{inorganic}$ in slurry is produced through mineralization of both urinary N and a limited fraction of the faecal N (Whitehead & Raistick, 1993). The $N_{inorganic}$ concentration of slurry is thus mainly determined by the total output of urinary N. As urinary N output can be strongly reduced by a reduction of the rumen degradable N surplus (Van Duinkerken *et al*., 2005), it is not surprising that low levels of $N_{inorganic}$ in the slurry were associated with low OEB levels (Table 6.7).

The $N_{organic}$ in slurry is the fraction of faecal N that is not mineralized. Slurry $N_{organic}$ might therefore be related to the concentration of N in the faeces. In the current study, this concentration ranged from 30 to 41 g kg^{-1} DM, consistent with values reported in other studies where dairy cows were fed with various mixtures of grass silages and concentrates (De Visser *et al.*, 1998; Bruinenberg *et al*., 2003; Sørensen *et al*., 2003). It is generally accepted that the concentration of faecal N is positive related to the digestibility of the diet (e.g. Mason, 1969; Kyvsgaard *et al*., 2000; Sørensen *et al*., 2003; Lukas *et al*., 2005). At first sight, the negative correlations between energy-related parameters (VEM, OM digestibility of grass silage) and slurry $N_{organic}$ contents (Table 6.7) seem to contradict with this relation. After a closer look, it appeared that faecal N concentrations (in accordance with the expectations) tended to be lower on diets with low energy contents (Figure 6.2; P=0.057) but that these lower values did not result in lower $N_{organic}$ concentrations in the stored slurry. In fact, the organic N concentration of stored slurry differed less from that in the faeces for the low compared to the high energy diets (Figure 6.2). This suggests a reduced mineralization of faecal N in the storage which is in agreement with the observation of Sørensen *et al.* (2003) that the mineralization rate of faecal N in slurry is influenced by the diet. In that study, lower rates were observed for diets containing larger fractions of fibrous material.

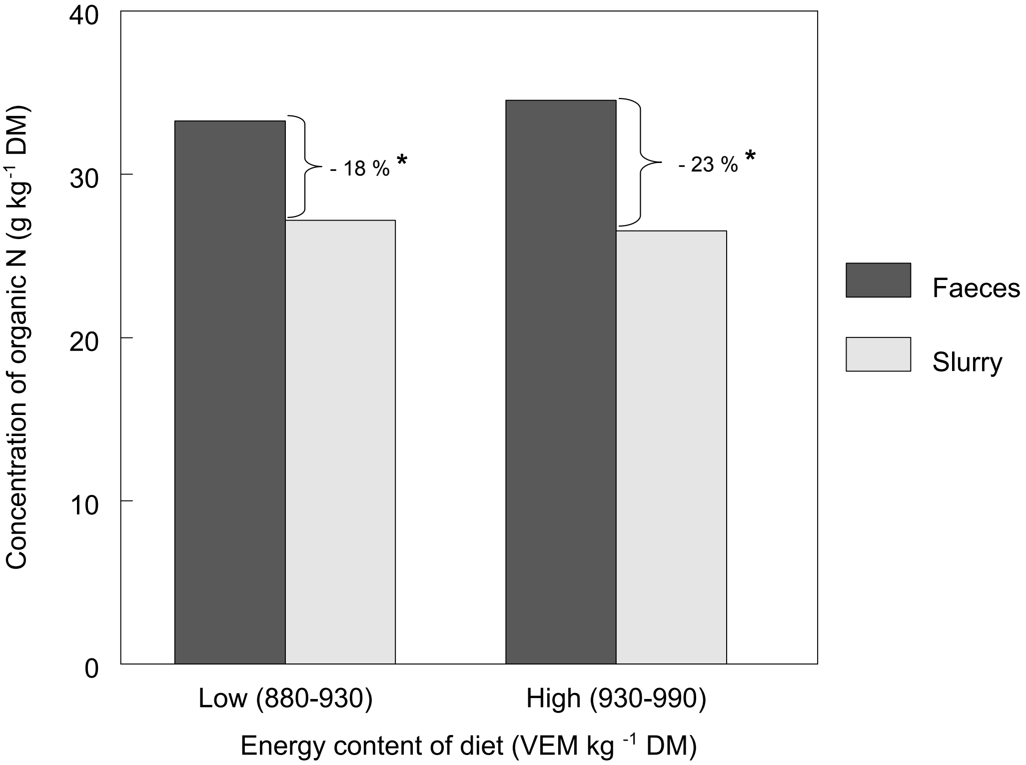


Figure 6.2 *Concentration of organic N in faeces and slurry on diets with low (880–930 VEM kg^{-1} DM) and high (930–990 VEM kg^{-1} DM) energy contents. * significant (P<0.05) difference between the two groups (N=12) in the reduction of the organic N concentration from faeces to slurry*

6.3.4 Effectiveness of diet adjustments: two groups of farms

To evaluate the effectiveness of the diet adjustments, the farms were divided into two groups. Group S represents farms where the costs for imported feeds stabilized or decreased in the course of the project. The farms where these costs increased were placed in group I (Table 6.2). Table 6.8 shows the development of diet composition and herd performance in the two groups.

The initial dietary protein content did not show any difference between the two groups since the CP content, OEB value and DVE supply were almost equal for both groups at the start of the project (Table 6.8). However, the energy content of the diet (VEM) contrasted in the initial situation. Through a larger use of concentrates in combination with a higher energy content of the grass silage, the average VEM content in group I was significantly higher than in group S (Table 6.8). Through this strategy the farmers of group I achieved in 1998/99 a (non-significant) higher milk production and a better performance in terms of feed N conversion (higher N efficiency, lower N excretion per kg FPCM, lower milk urea contents; Table 6.8). The farmers of group S showed a (non-significant) lower N excretion per cow. Summarizing these differences in the initial situation, we conclude that the farmers of group S were already focused on a maximal use of homegrown forage at the start of the project whereas the farmers of group I did put more emphasis on an increased production per cow through a higher use of concentrates.

As a result of the changes in grassland management triggered by the NMP, grass silage composition of both groups has considerably changed compared to the initial situation. Both groups of farms have adopted the typical V&V strategy in silage making (Figure 6.3). The energy content of the grass silage (VEM) decreased for both groups, but the decrease was larger for group I (Figure 6.3). The CP content also decreased for both groups but here the decrease was larger for group S (Figure 6.3). These changes resulted in a significantly lower CP : VEM ratio of grass silage for group S compared to group I (Figure 6.3, Table 6.8). For both groups, the average DVE value of the grass silage decreased to 68 g kg^{-1} DM (Table 6.8). However, the OEB content of the grass silage was significantly lower for group S. The farmers of group S, that were already focused on an maximal use of homegrown forage, clearly succeeded better in the production of grass silages with the desired characteristics.

Table 6.8 *Mean dietary characteristics and herd performance in the monitored period (2001-2004) relative to the initial situation (98/99), for the farms that decreased/stabilized (S, n=7) or increased (I, n=5) yearly feed costs per kg FPCM during the course of the project.*

Diet composition					*Herd performance*				
Year	98/99^{d}		01-04 ^{d}		Year	98/99 ^{d}		01-04 ^{d}	
Farm group	S	I	S	I	Farm group	S	I	S	I
Whole diet					Productive performance				
DMI (kg DM cow^{-1} day^{-1})	19.0	20.5	19.6	20.2	Milk (kg cow^{-1} day^{-1})	24.1	26.8	23.4	25.7
Concentrates (% of DM)	31	39	32	37	- fat (% of milk)	4.45	4.43	4.60	4.49
Concentrates (kg 100 kg^{-1} FPCM)	23	28	25	27	- protein (% of milk)	3.48	3.46	3.52	3.43
CP (g kg^{-1} DM)^{e}	174	173	152 **	165 **	- lactose (% of milk)	4.52	4.50	4.51	4.51
OEB (g cow^{-1} day^{-1})	517	546	138 **	361 **	- urea (mg dl^{-1})	24.4	21.4	20.3 **	22.7 **
DVE (% of requirement)	112	111	112	114	FPCM (kg cow^{-1} day^{-1})	25.5	28.3	25.2	27.2
VEM (kg^{-1} DM)	940 *	969 *	929	949	Milk N (g cow^{-1} day^{-1})	131	145	129	138
CP:VEM ratio ^{e}	0.185	0.178	0.164 *	0.174 *					
N intake (g cow^{-1} day^{-1})	529	565	475	534					
					Economic performance				
Grass silage					Margin^{a} (€ 100 kg^{-1}FPCM)	n.a.	n.a.	28.8 *	27.4 *
CP (g kg^{-1} DM)^{f}	171	175	143 *	151 *	Margin^{a} (€ cow^{-1} day^{-1})	n.a.	n.a.	7.26	7.44
VEM (kg^{-1} DM)	875	889	850	846					
DC_{OM} (%)	n.a.	n.a.	74.1	74.5	Environmental performance				
CP:VEM ratio ^{f}	0.196	0.197	0.168 **	0.179 **	N excretion^{b} (g cow^{-1} day^{-1})	394	416	346 *	396 *
DVE (g kg^{-1} DM)	73	74	68	68	N excretion^{b} (g kg^{-1} FPCM)	15.6	14.7	13.8	14.6
OEB (g kg^{-1} DM)	45	52	16 *	26 *	N efficiency^{c} (%)	24.8	25.8	27.1	25.7

a) Calculated as milk returns minus costs for imported feeds

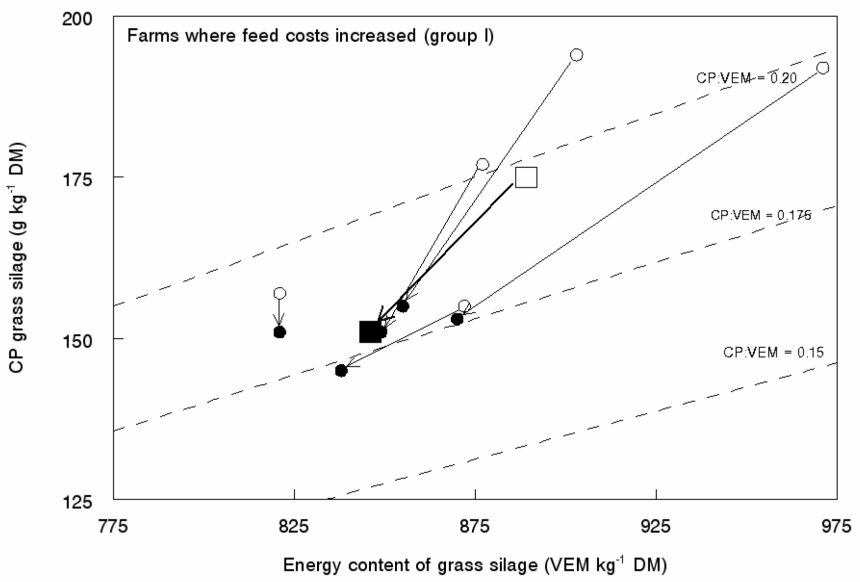
b) Calculated as N ingested with feed minus N in milk minus N retention

*c) Calculated as (N in milk / N ingested with feed) * 100 %*

*d) Statistically significant between groups within the same period: * = $P < 0.05$; ** = $P < 0.01$*

*e) Including ammonium fraction of grass silages, calculated as (N intake * 6.25) / DMI.*

f) Ammonium fraction not included



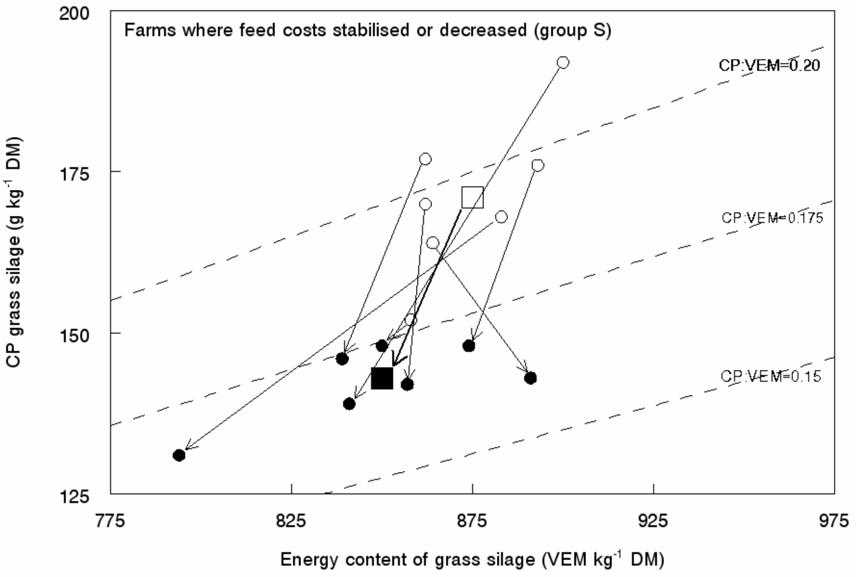


Figure 6.3 *The development of grass silage composition from 98/99 (○ individual farms; □ average) to 2001–2004 (● individual farms; ■ average) on farms where feed costs increased (group I, n=5) and farms where feed costs stabilised or decreased (n=7) in the course of the project*

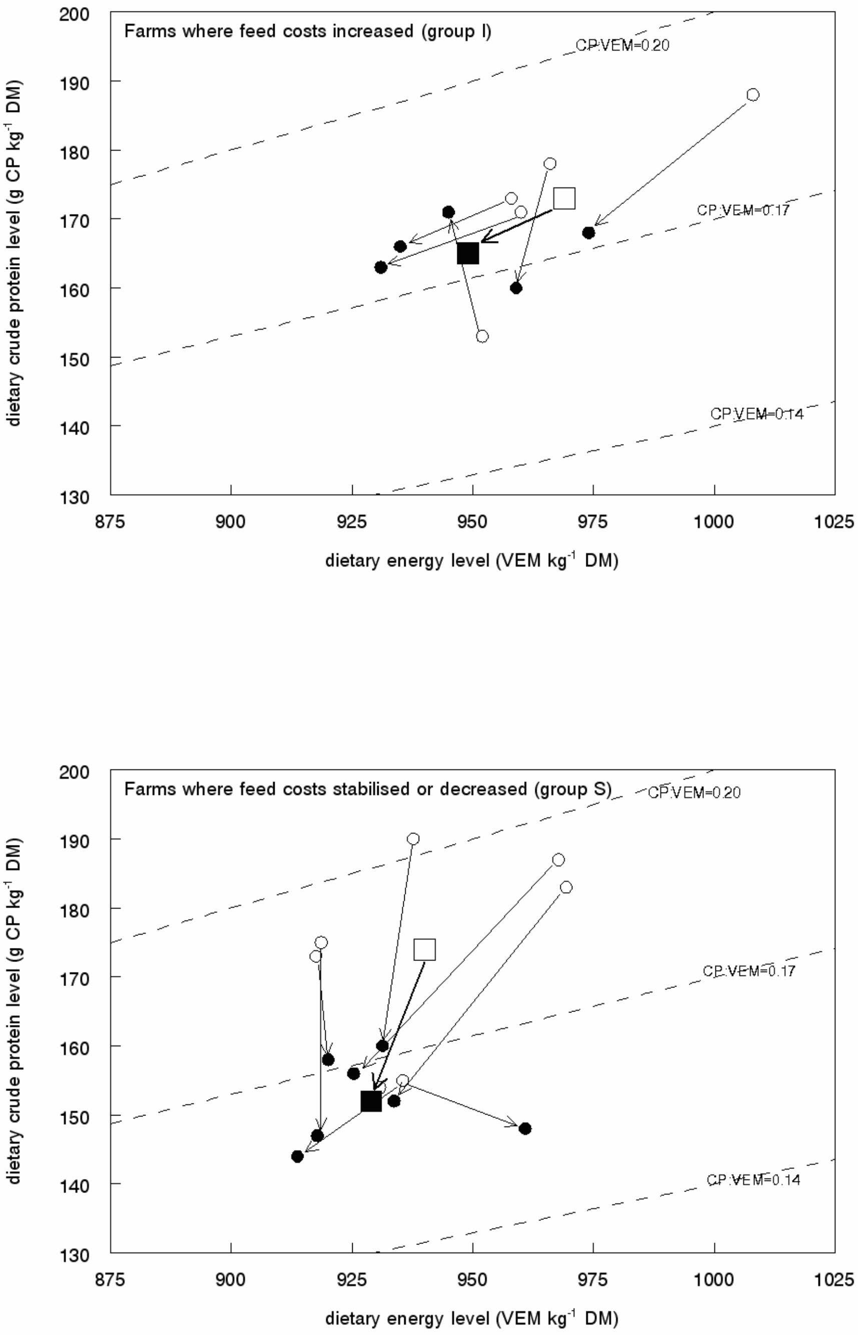


Figure 6.4 *The development of diet composition from 98/99 (○ individual farms; □ average) to 2001–2004 (● individual farms; ■ average) on farms where feed costs increased (group I, n=5) and farms where feed costs stabilised or decreased (n=7) in the course of the project*

For group S, the changed grass silage composition has resulted in a strong reduction of CP (and OEB) and a slight decrease of the energy content of the whole diet (Figure 6.4). The percentage of concentrates remained at the same level. DVE supply was not reduced. The average CP : VEM ratio of the whole diet on these farms decreased drastically (from 0.185 to 0.164, Table 6.8). These changes in diet composition have resulted in a slightly lower milk production compared to the initial situation but through the increased fat and protein content, FPCM production remained at the same level. For this group, the changed grass silage composition resulted in an improved environmental performance. N excretion decreased with more than 10% and the N efficiency increased from 24.8 to 27.1% (Table 6.8). As this improvement was accompanied by a stabilization/decrease of the feed costs, the diet adjustments were evaluated as effective.

In group I, however, the changes in grass silage composition resulted in a large decrease of the energy content of the whole diet and only a minor decrease of the CP content (Figure 6.4). The percentage of concentrates used decreased slightly. The decrease of OEB stagnated whereas the DVE supply even increased. The CP : VEM ratio of the whole diet decreased only marginally (from 0.178 to 0.174, Table 6.8). On these farms the grass silages with lower levels of energy and protein, in combination with the reduced concentrate use, induced a lower level of milk protein production. The farmers tried to compensate this drop in production by adjusting the type and amount of concentrates (in particular increasing the CP content of concentrates) but without the desired success. Environmental performance did not improve on these farms. The decisive factor in this appeared to be the capability to maintain milk protein production. Whereas in group S, a 9% reduction in N intake resulted in only a 2% reduction in milk N yield, the reduction in N intake (4%) in group I coincided with a 5% reduction in milk protein production. As the feed costs increased and the environmental performance did not (Table 6.2) the diet adjustment that the farmers of group I have implemented were not effective.

6.3.5 Evaluating the re-balancing strategy

The re-balancing strategy of the V&V project was adapted to prevailing local conditions: it was based on the management practices and ideas of local farmers, enriched with a ‘relatively new’ theoretical framework presented by Van Bruchem *et al.* (1999a). The basis of the proposed diet adjustments was to reduce the protein and increase the fibre content of the diet through a shift in grass silage composition. In the NMP, this particular strategy was promoted and the farmers in this study largely adopted it (Figure 6.3). All farms succeeded in a strong reduction of the MINAS N surplus and the desired reduction of the slurry $N_{inorganic} : N_{total}$ ratio was achieved. The presented data of group S (Table 6.8) showed that the described strategy can be an effective instrument to reduce the N surplus of grassland based dairy farms. However, the proposed diet adjustments were definitely not effective on all farms, as shown by the results of the farmers of group I (Table 6.8).

Through their management decisions over the years, farmers adapt the characteristics of available resources and their interrelations. The actual performance of farms is the 'state-of-the-art' of this long-term and ongoing fine-tuning process. As personal characteristics and objectives are important determinants of management decisions (Rougoor *et al.*, 1998; Ondersteijn *et al.*, 2003b), this optimization is a highly individual process. The specified re-balancing strategy in the NMP was, however, not explicitly adapted to individual preferences and capabilities of farmers and farm characteristics. In the initial situation (Table 6.8), the farmers of group I were further away from the proposed guidelines (Table 6.1) than farmers of group S. For group I, the change to the diet composition proposed by the NMP appeared to be more than just changing the composition of grass silage. It required a shift of the complete production system created in the past, merely based on the use of external concentrates, which appeared to be a difficult task. The farmers of group S, however, who were in the initial situation already focused on a maximal use of homegrown forage, had probably already adapted their way of intervention towards the diets suggested in the V&V project. As the dietary changes proposed in the NMP were not in conflict with their original strategies, they succeeded better in the production of grass silages with the desired characteristics (low CP : VEM ratio and OEB content) and they could implement the proposed adjustments successfully.

Defining a strategy can be helpful as it gives direction to the way a farm implements management changes. However, the strategy itself does not explain differences in farm performance. There might be different, mutually contrasting strategies that help to reach, in the end, the same objectives. Ondersteijn *et al.* (2003b) concluded that environmental improvements can be achieved regardless of the way a farmer chooses to develop his or her farm. Farm performance is rather determined by the ability of the farmer to actually create a coherent set of resources, consistent with this strategy. As the farmers of group I in the initial situation composed diets with high energy contents, probably alternative strategies to increase feed N conversion such as the use of maize or cereal silages or low protein concentrate feeds in combination with high digestible grass silages might have fitted better with the characteristics of the farms and farmers of group I. We conclude that, to prevent disappointing results as those observed for the farmers of group I, feeding strategies should be always be differentiated for individual farmers and integrated in a whole farm nutrient management perspective (Rotz *et al.*, 2005), taking specific capabilities and objectives of the farmer into consideration.

6.3.6 The scope of decreasing N excretion

Excess protein feeding results in an increased excretion of N with faeces and urine, potentially contributing to environmental pollution. The Dutch protein evaluation system has been developed to prevent excess protein feeding to dairy cows (Tamminga *et al.*, 1994). This system has been in use in the Netherlands from 1991 onwards. However, in line with the C&O project and despite their efforts, also the farmers in the present study still largely exceed the optimum values defined by the Dutch system (OEB 0, DVE supply 100%) according to Table 6.8.

Figure 6.5 shows that an enormous variation existed in the excretion of N per kg of milk (FPCM) produced. Further, this figure indicates the large potential to decrease the amount of manure N produced from dairy farming without having adverse effects on milk production. Besides, it shows that a reduction of N excretion per kg milk produced does not necessarily require a certain level of milk production as N excretion per kg milk is highly variable at a large range of milk production levels (22–32 kg FPCM, Figure 6.5). This implies that indeed various strategies can be followed to obtain a reduced N excretion.

The variation in N excretion per kg FPCM in the present study appeared to be strongly related to the excess of protein calculated with the Dutch protein evaluation system (Tamminga *et al.*, 1994). Linear regression revealed that the combination of DVE supply and OEB explains a major part of this variation, according to the following equation:

$$N\ excretion\ (g\ kg^{-1}\ FPCM) = -2.35\ (\pm\ 0.91) + 0.137\ (\pm\ 0.008) * DVE\ supply\ (\%) + 0.0039\ (\pm\ 0.0004) * OEB\ (g\ cow^{-1}\ day^{-1})\ (adj.\ R^2 = 0.82) \tag{6.8}$$

Filling in the optimum values of the system (DVE supply 100% and OEB 0 g cow^{-1} day^{-1}) in this equation, results in a minimum N excretion of 11.4 g kg^{-1} FPCM. Hypothetically, when the farmers in this study would have succeeded to achieve the theoretically optimum levels of DVE supply and OEB, this would have resulted in a reduction of the manure N production of approximately 20% compared to the actual situation. With an average milk production of 11.7 Mg FPCM ha^{-1} this corresponds with a reduction of 33 kg N per hectare. As the total milk production in the Netherlands amounts to about 11.5 billion kg FPCM $year^{-1}$, such a reduction would decrease the total production of N in dairy cow manure in the Netherlands with 32 million kg N $year^{-1}$.

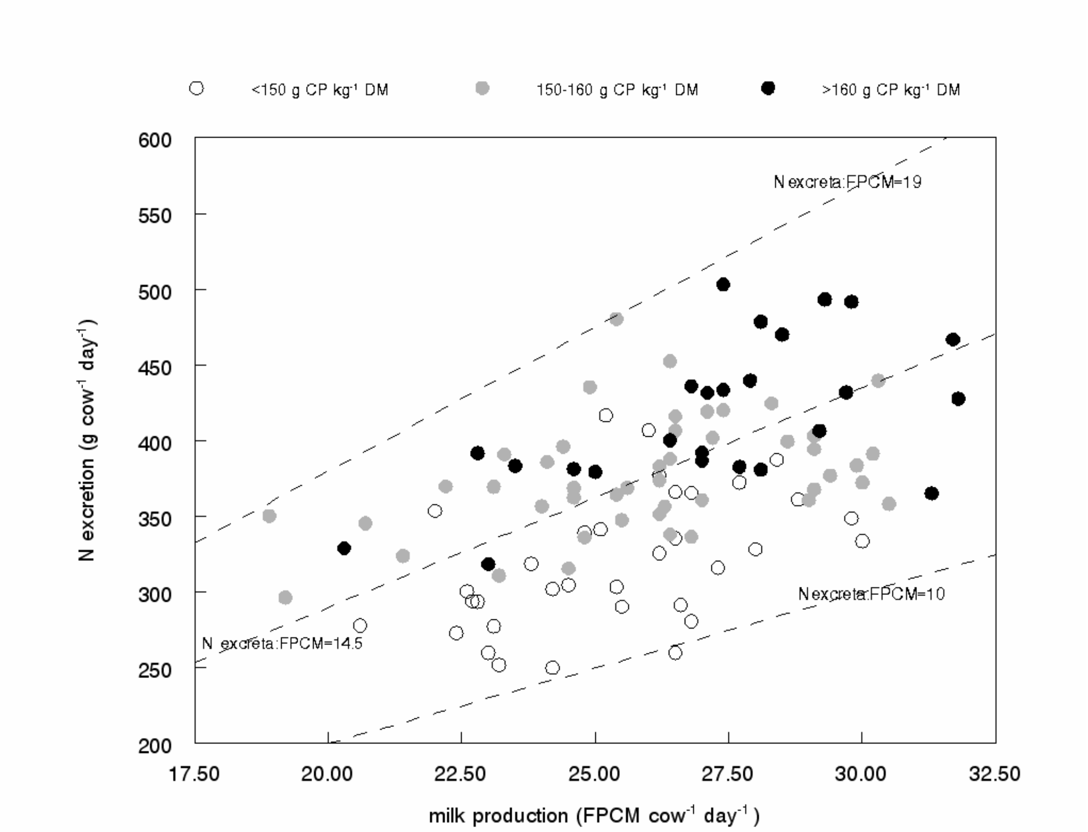


Figure 6.5 *N excretion (g cow^{-1} day^{-1}) in relation to the level of milk production (kg FPCM cow^{-1} day^{-1}) for winter diets containing <150 g CP kg^{-1} DM (○), 150–160 g CP kg^{-1} DM (●) and >160 g CP kg^{-1} DM (●) on 12 VEL and VANLA farms in the period 2001–2004. The dotted lines indicate different levels of N excretion per kg FPCM produced*

The strong potential to reduce protein feeding is in agreement with results of various studies showing that a strong reduction of dietary protein need not to have significant effects on milk yield per se (e.g. Kröber *et al.*, 2000; Castillo *et al.*, 2001; Kauffman & St-Pierre, 2001). However, other studies do show a reduced milk production with a decrease of the dietary CP content (e.g. Kalscheur *et al.*, 1999; Broderick, 2003; Ipharraguerre & Clark, 2005), especially for high producing dairy cows and cows in early lactation. It should be realized that the response in milk production to an increase in substrate availability will be of the diminishing returns type. A drop in milk production as a result of reduced protein feeding will be more pronounced when already low levels of protein are fed. Current protein evaluation systems though are requirement based and can not predict milk production changes in response to a change in dietary protein concentration (Dijkstra *et al.*, 2007a).

Feeding excessive protein in theory increases feed costs. Indeed, in the current study a negative correlation between feed margin and the dietary protein content was observed (Table 6.6). It is, however, generally presumed that the economic costs of underfeeding protein exceeds the costs of excess feeding (VandeHaar & St-Pierre, 2006) as underfeeding may result in a drop of milk production or milk protein content. Milk returns are largely dependent on the milk protein content. Interviews with the involved farmers clearly revealed that fear for a drop in the milk protein content is the major reason to feed excess protein as a margin of safety. Reduction of feed protein supply is therefore in the first place hampered by economic motives.

In addition, there is also a number of technical issues that complicate the reduction of protein feeding. First of all, both intestinal supply of and requirements for the production of individual amino acids are still difficult to predict (Børsting *et al.*, 2003; Dijkstra *et al.*, 2007a) and therefore our ability to predict the response of dairy cows to protein is limited as shown by Santos *et al.* (1998). This might improve with future nutrient based feed evaluation systems that take interactions between feedstuffs on the one hand and between the feed and the animal on the other into account (Bannink *et al.*, 2007). Furthermore, high producing dairy cows in early lactation can use rumen undegradable protein as an energy source for the production of lactose. In this way, feeding excessive rumen undegradable protein can result in a higher milk production by disguising a shortage of glucogenic nutrients that often occurs on grass silage based diets (Dijkstra *et al.*, 2007b) or in early lactation (Van Knegsel *et al.*, 2005). A third aspect mentioned here is that grass based diets often lack sufficient rumen available energy to capture the available N. As shown in this study, an optimal balance between rumen available energy and protein in the grass itself is therefore an important precondition for a successful reduction of protein feeding in this kind of systems. This balance can be strongly improved by a decrease of the fertilization level, provoking an exchange of CP for water soluble carbohydrates (Peyraud & Astigaragga, 1998). Obtaining this balance requires not only favorable weather conditions, but also good grassland management skills.

6.4 Conclusions

Triggered by the participation in the project, the farmers in this study have substantially altered the composition of the cow's diets. The typical reduction of energy and especially protein level in the grass silages was widely adopted. The aimed increase of the slurry C:N_{total} ratio together with a reduction of the slurry $N_{inorganic}$: N_{total} ratio was achieved. It was made plausible that this latter reduction was the combined effect of a reduced urinary N output with low protein diets and a reduced mineralization of faecal N in the slurry storage with low energy diets.

Excessive protein feeding was substantially reduced but the data showed still a large potential for a further reduction of the excretion of N per kg milk produced. To achieve this, feeding strategies should be focused on a decrease of the protein to energy ratio, especially that of the homegrown forage. On average, the diet adjustments proposed by the project were associated with a slightly lower milk production per cow but reduced N excretions and higher economic margins per kg milk produced. The proposed strategy can therefore be an effective instrument to reduce N excretion from dairy farms aiming at a moderate production level and a maximum use of homegrown grass.

The success in terms of economic and environmental performance appeared to be variable. On farms with increased feed costs in the course of the project, characterized by high dietary energy contents in the initial situation, also the environmental performance was not improved as the limited reduction in total N intake coincided with a similar reduction in milk protein production. On these farms, other strategies to reduce N excretion such as the use of maize or cereal silages or low protein concentrate feeds in combination with high digestible grass silages might have given a better performance. To avoid such disappointing results, the definition of feeding strategies should be individually differentiated and integrated in whole-farm nutrient management plans.

Chapter 7

General Discussion

7.1 Introduction

At the end of the 1990s the farmers of the VEL and VANLA environmental co-operatives were searching for measures to reduce the N surpluses from their farms, appropriate to their local situation. The VEL and VANLA region is characterized by a man-made landscape, consisting of small parcels of permanent grassland surrounded by hedgerows. The preservation of this landscape was and still is of major importance to the area as well as the farmers. For this and other reasons the production of maize silage, highlighted as a possible route to improve N efficiency (e.g. Korevaar & Den Boer, 1991; Aarts, 2000) was not attractive to these farmers. An initial analysis of the N flows of the farms in the area (Textbox 2.1) revealed that some of them combined low N surpluses with high production levels. These farmers became interesting examples for the others. According to them, differences in surpluses between farms were related to the presence of what they referred to as a "particular balance within the farm". At the same time, Jaap van Bruchem expressed the hypothesis that the reduction of N surpluses from dairy farms required a holistic perspective and an increase of the $C:N_{total}$ ratio of slurry by feeding diets with reduced energy and protein levels (Van Bruchem & Tamminga, 1997; Van Bruchem *et al.*, 1999a; Van Bruchem *et al.*, 1999b).

The acquaintance between the VEL and VANLA farmers and Jaap van Bruchem resulted in the start of a nutrient management project in 1998, which was the origin of this thesis. The project combined multiple deviations from the prevailing socio-technical regime (Chapter 1) and as a consequence of that it has been contested from the beginning both in scientific circles and in farming practice (Eshuis & Stuiver, 2005). However, the characteristic soil-plant-animal-manure picture (Figure 2.2) was an eye-opener for many farmers as it visualised the nutrient flows and the importance of internal resources on a dairy farm in an accessible way. Most farmers in the project were quite enthusiastic about the approach and the results of the project in terms of MINAS N surpluses were highly promising (Chapter 2). One of the major reasons for the controversy about the project is that the underlying hypotheses (Van Bruchem *et al.*, 1999a; Van Bruchem *et al.*, 1999b) were poorly founded in and supported by scientific evidence. Questions popped up almost continuously about the validity of the hypotheses of the project, both from inside and outside the project. Testing of these hypotheses was complicated due to their holistic character and the different frames of reference of ‘contesters’ and ‘believers’ but this complication does not dispense the project from the obligation to search for valid answers. This thesis sought to find relevant answers to questions raised about one of the main topics in the project:

The idea that the composition of slurry can be modified by means of diet adjustments and that this modification contributes to reduced N losses from grassland-based dairy farms.

The hypothesis that dietary adjustments can change slurry composition which contributes to reduced N losses is regarded as a novelty; that is a new configuration that promises to work (Rip & Kemp, 1998).

7.2 Studying a novelty

The hypothesis of the VEL and VANLA project was multi-facetted. From the toolbox of management measures that was defined in the project (Chapter 2), the described novelty was selected as the object of study. From the definitions of a novelty (Van der Ploeg *et al.*, 2004; Van der Ploeg *et al.*, 2006) four key characteristics of a novelty can be derived:

1. A novelty is a configuration, result or insight observed in practice
2. A novelty contains the promise of a shift in established patterns
3. A novelty is ignored by the prevailing regime
4. A novelty is not yet fully understood

The defined novelty fulfilled these four criteria perfectly. It was observed in practice: during the 1990s there were farmers in the Netherlands that paid a lot of attention to the improvement of slurry composition (Anon., 1995; Van der Ploeg, 2003, pp. 205–206). They recognized dairy slurry as a valuable resource and tried to increase its value by adapted feeding management, the use of additives or changed bedding material. These practices involved the promise of a regime shift as they were completely focused on an improvement of internal resources which had been ignored as a valuable source of nutrients for a long time during the modernization trajectory (Chapter 1). During the 1990s the effect of nutrition on slurry composition was not (yet) recognized by the prevailing regime. Obviously, there has been attention for possibilities to reduce N losses by means of nutrition management (e.g. Van der Meer, 1991; Tamminga, 1992) and from slurry storage and application (e.g. Van der Meer, 1991), but the first Dutch report on the relationship between animal nutrition and manure quality was published not before 2000 (Velthof *et al.*, 2000). It concluded that the quantitative understanding of the relation between the ration composition and the availability and stability of the various C, N, P and S compounds in the manure was still poor (Velthof *et al.*, 2000). With this conclusion the fourth criterion also holds. Thus, I focused on the relation between diet adjustments and slurry composition and how this relation affects the farm management.

Most of the work presented in this thesis is of a technical nature. However, through the use of the concepts ‘novelty’ and ‘regime’ from the field of technology & society studies (Rip & Kemp, 1998), social and technical aspects of reducing N surpluses were adressed in an integrated perspective. As a consequence of this integrated beta-gamma approach the research questions in this thesis were primarily based on observations within farming practice itself which is in contrast to many technical research projects that mainly depart from earlier scientific findings. As a result, questions about the relevance of research outcomes for farming practice were already addressed at an early stage and continuously repeated. Moreover, this approach required the use of on-farm data whereas a large part of the agronomical research during the last decades was based on controlled experiments, model simulations and desk studies. The main advantage of the presented approach is that it ensures to deal with real-world problems and real-world solutions. Possible disadvantages of on-farm agronomical research are that the required level of detail is missing in the available information or that the opportunity to test hypotheses in a controlled environment is lacking. To overcome these disadvantages, this thesis made use of a multi-method approach. On farm monitoring (Chapter 6) was supported by experiments under controlled conditions (Chapter 3 and 4) and model simulations (Chapter 5). With this approach, I aimed to provide useful knowledge on the potential contribution of the described novelty to a further reduction of N losses from Dutch dairy farming.

7.3 Evaluation of the novelty

7.3.1 Feeding strategies and N excretion

Each transfer event of manure N in the dairy farm provides a risk for N losses to the environment. Reduction of the amount of manure N per kg milk produced tackles these losses at the source without entailing a risk for pollution swapping. The empirical data of Chapter 6 show that the excretion of N in manure can be reduced to values as low as 10 gram per kg FPCM whereas a theoretical lower boundary of 11.4 was derived. With the current legislation, that restricts the use of manure N per hectare, feeding theoretically optimum levels of dietary protein could increase the potential productivity (milk production per ha) of individual farms by more than 20% compared to the average situation in the Netherlands (Tamminga *et al.*, 2004).

From my experiences with the farmers in the VEL and VANLA project, it is obvious that there is a tremendous variation amongst farmers in the goals and objectives they have and the optimum level of milk production they aim at when composing the diets of their cows. To a certain extent, these differences are related to variations in farm characteristics like the intensity, the ability and willingness to grow maize, cheap access to ‘nature’ land for forage production, the type of cows etcetera, but also personal preferences of farmers are crucial in the management goals farmers aim at and the strategies they develop (Van der Ploeg, 1996; Rougoor *et al.*, 1998). As a reduced N excretion can be achieved irrespective of the level of milk production per cow (Figure 6.5), such a reduction does not necessarily narrow down the possibilities for the farmer with respect to the optimum level of milk production.

Both the model simulations of Chapter 5 and the empirical data of Chapter 6 revealed that N excretion can be lowered by the reduction of the dietary CP:VEM ratio (Figure 7.1).

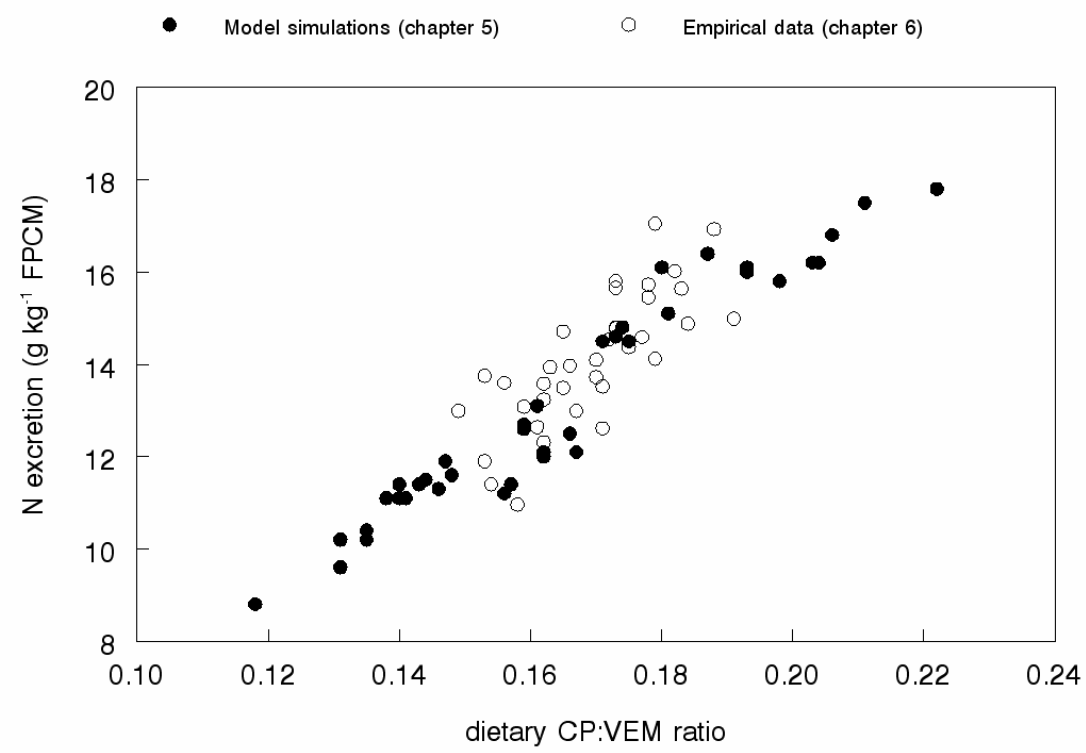


Figure 7.1 *Relation between the dietary CP:VEM ratio and N excretion per kg FPCM simulated in Chapter 5 and observed in Chapter 6*

Feeding strategies to reduce N excretion should therefore focus on a decrease of this ratio. This can be achieved by various strategies. The strategy promoted in the VEL and VANLA project aimed at a reduced N fertilization and a postponement of the cutting stage of grass. On the monitored farms this strategy resulted in reduced CP:VEM ratio's of grass silage as the reduction in CP content obtained was larger than the reduction in VEM content (Chapter 6). The dietary changes proposed in the project were associated with reduced N excretions and higher economic margins per kg milk produced but slightly lower levels of milk production per cow (Table 6.1). The strategy proposed in the VEL and VANLA project can therefore be an effective instrument to reduce N excretion from dairy farms with predominantly grassland that aim at a moderate milk production level.

However, it turned out in Chapter 6 that the success of VEL and VANLA strategy appeared to be variable on the monitored farms. Whereas one group of farms increased the environmental performance in combination with a decrease or stabilization of the feed costs, other farms showed increased feed costs without improvement of the environmental performance. On the latter farms, that were characterized by high dietary energy contents before the strategy was introduced, the proposed strategy apparently did not match with the mode of production and intervention that has been established. These farmers probably should have been better off with other feeding strategies such as the use of maize silage and/or low protein concentrates in combination with high digestible grass silages. It is concluded that the effectiveness of feeding strategies does not depend on the strategy itself, but rather on the ability of the farmer to 1) select that strategy that fits best with his or her capabilities and the characteristics of the farm, and 2) to adjust the characteristics of internal resources (i.e. homegrown forage) in such a way that they are consistent with this strategy.

7.3.2 Diet adjustments and slurry composition

Chapters 4, 5 and 6 all show that the composition of slurry N is variable and that this variation is related to the composition of the diet. The farmers of the VEL and VANLA project succeeded in the aim to increase the C:N_{total} ratio of slurry. The simulated and observed C:N_{total} ratio in Chapters 4 and 5 ranged from 4.4 to 11.9 (Table 7.1). The lowest values are not likely to be observed in practice as these values were associated with unusual large protein surpluses.

Table 7.1 *Mean values and ranges of slurry characteristics in Chapters 4, 5 and 6 compared to the national average in the period 2001–2006 (Reijneveld, personal communication)*

Slurry characteristic	*Chapter 4 (animal experiment)*	*Chapter 5 (model simulations)*	*Chapter 6 (empirical data)*	*National average*
C:N_{total}	8.0 (5.1–11.4)	7.7 (4.4–11.9)	8.9 (7.3–11.8)	8.4
$N_{inorganic}$ (g kg^{-1} OM)	45 (24–64)	33 (14–64)	28 (17–37)	34
$N_{organic}$ (g kg^{-1} OM)	27 (19–47)	29 (23–35)	35 (29–42)	29
$N_{inorganic}$: N_{total} (%)	61 (51–73)	52 (34–65)	45 (34–54)	53

The highest values were indeed observed in the empirical dataset of Chapter 6 (Table 7.1). Incidentally, somewhat higher values have been observed (Chapter 3), but values of 12 to 13 seem to represent the absolute maximum value for lactating cows (Lantinga, 2000; Sørensen *et al.*, 2003). Obtaining these high C:N_{total} ratio's in the slurry requires both a low N excretion as a result of low protein contents and a high OM or C excretion as a result of a low overall diet digestibility (Chapter 5). This can be attained by various strategies such as the use of low digestible grass silages as proposed in the

VEL and VANLA project but also by the inclusion maize silage, cereal silages or straw in the diet.

The VEL and VANLA farmers also succeeded in the aim to reduce the $N_{inorganic}$: N_{total} ratio of the slurry (Chapter 2 and 6). Whereas an increase in slurry C:N_{total} ratio is commonly observed with reduced protein feeding, the reduction of the $N_{inorganic}$: N_{total} ratio was not observed in the Cows & Opportunities project (Oenema, personal communication) nor at the national level (Table 7.1). The empirical data in Chapter 6 clearly suggested that the typical adjustments of diet and grass silage proposed in the VEL & VANLA project played a crucial role in the reduction of the latter ratio (Table 6.7). It was argued that the relatively large reduction of this ratio might have been caused by a reduced mineralization rate of faecal N in the slurry storage with low energy diets. In the dataset of Sørensen *et al*. (2003) the mineralization of faecal N was also affected by the dietary fibre content in this way. However, to draw firm conclusions on the detailed mechanisms behind this process, it needs to be studied more elaborately in other datasets and/or under controlled circumstances.

In general terms, it has been shown that the reduction of excessive protein feeding results in increased C:N_{total} ratio's and decreased $N_{inorganic}$ concentrations in slurry. However, it was also demonstrated that the effect of dietary changes on excreta composition is detailed and complex. The modelling approach presented in Chapter 5 takes this complexity into account and further development and testing of this model can result in a powerful instrument to evaluate the consequences of changes in diet composition on the composition of manure.

7.3.3 Slurry composition, N availability and N losses

Manure conversion processes after field application are determined by the interaction of numerous factors such as manure composition but also other factors like crop type, application rate and timing, soil characteristics and weather conditions (Schröder *et al*., 2006). Chapter 4 showed that even between replicate treatments on the same field variation in N uptake can be large. Within this variation it was shown that the plant availability of field-applied N is related to the composition of slurry. The actual utilization of slurry N after field application will largely depend on the management skills of the farmer and the specific conditions during application. However, the field experiment of Chapter 4 is used here to illustrate the potential consequences of the differences in slurry composition simulated in Chapter 5 on the destination of slurry N following field application. This is relevant as slit-injection on grassland is the major route of slurry application in the Netherlands.

In this example, three final destinations of slurry N in the year of application were distinguished. First, the total loss of ammonia N was calculated as the sum of the simulated ammonia N losses in the storage pit (Chapter 5) and the ammonia losses following application which were estimated as a constant percentage of 20% of the inorganic N applied (average N emission for shallow injection; Huijsmans *et al.*, 2007). Second, the potentially plant available fraction of slurry N (available N) was based on the MFE (Mineral Fertilizer Equivalent) estimated as a linear function of the simulated slurry C:N_{total} ratio, based on data from the NEW field in Chapter 4. The remainder of the slurry N resides in the soil, contributing to the organic N soil pool and is labelled as (residual) soil N. Total annual manure N use was set at 278 kg N ha^{-1} yr^{-1}, i.e. the allowed ceiling dosage of 250 kg N ha^{-1} yr^{-1} according to the EU Nitrate Directive for farms with an individual derogation (European Community, 2005) plus a standard storage loss of 11.25% (28 kg N ha^{-1} yr^{-1}, Oenema *et al.*, 2000).

Figure 7.2 illustrates that increasing the C:N_{total} ratio of slurry will cause a substantial shift in the destination of the excreted N. According to these calculations an increase of the C:N_{total} ratio from 6 to 12 will result in a reduction of the amount of plant available N of approximately 35 kg N ha^{-1} yr^{-1} and a reduction of the N losses with ammonia of approximately 25 kg N ha^{-1} yr^{-1}, resulting in an increase of 60 kg residual soil N per ha per year. This residual N can become available for plant growth through mineralization in the following years. The model simulations of Chapter 4 suggested that it might take decades before the total annual amount of yearly available N from slurry and soil together using slurry with a high C:N_{total} ratio equals that from slurry with a low C:N_{total} ratio. Farmers who opt for an increase of the C:N_{total} ratio of cattle slurry should be aware of this reduction.

Actual losses of ammonia N from cow houses are determined by many factors (Sommer *et al.*, 2006). In line with the experimental results of Van Duinkerken *et al.* (2005) the model simulations in Chapter 5 revealed that ammonia N losses per cow or per kg milk produced from cow housing can be reduced by more than a factor 2 through diet adjustments. However, other experiments revealed a more limited effect of diet adjustments on ammonia emission from cow housing (Misselbrook et al., 2005a). According to Figure 7.2, a doubling of the slurry C:N_{total} ratio from 6 to 12 reduces the total ammonia N emission from storage and application by about 40% of the excreted N (from 60 to 35 kg N ha^{-1} yr^{-1}). In this example the reduction of ammonia emission from field application might have been slightly overestimated as it was shown in Chapter 4 that ammonia losses of slit-injected slurry with a high C:N_{total} ratio might be higher than expected from its $N_{inorganic}$ content due to an increased DM content.

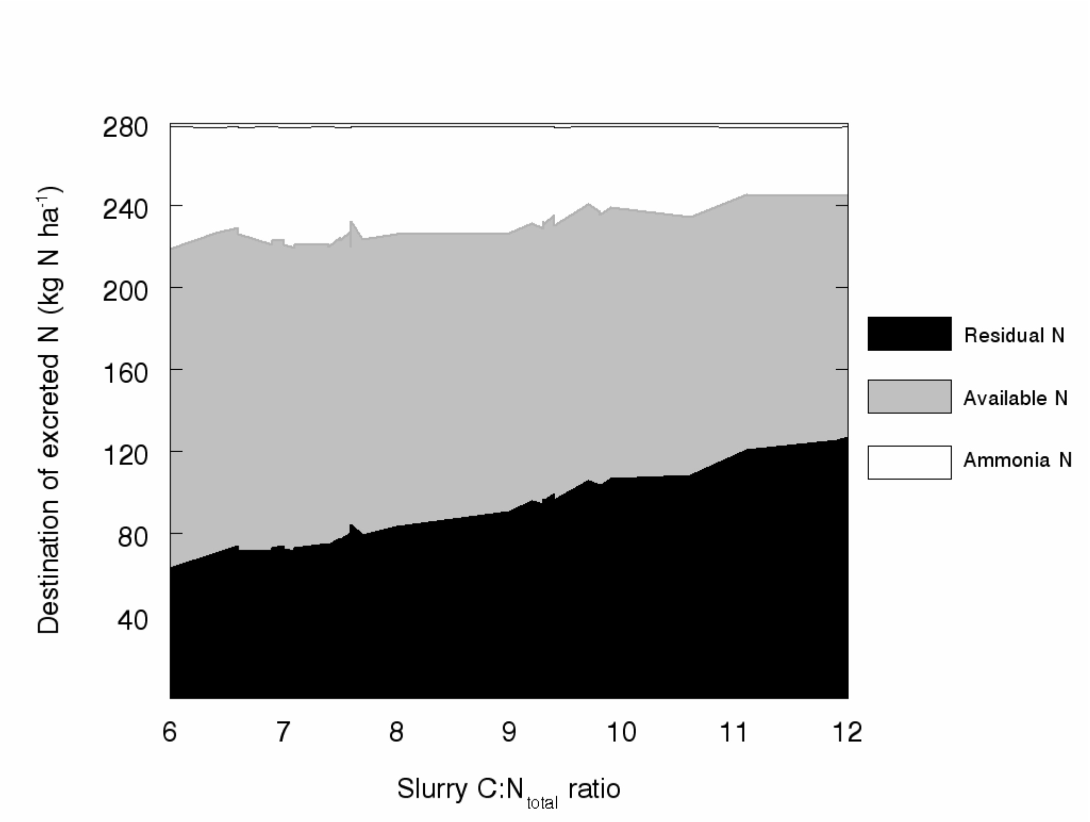


Figure 7.2 *Illustration of the effect of the range in slurry C:N$_{total}$ ratio simulated in Chapter 5 on the destination of excreted N in the growing season after spring and early summer application on grassland divided into: total ammonia N losses (ammonia N), plant available N (available N) and residual soil N (residual N) in kg ha^{-1} yr^{-1} (see text for further explanation)*

In theory, increased soil N mineralization as a result of the higher residual N effects of slurry with a high C:N ratio (Figure 7.2) will increase the risk for N losses with leaching. However, nitrate leaching under grassland depends rather on the total N application rate than on the rate of application of manure N (Ten Berge *et al.*, 2002). Therefore, when total N application rates are adjusted for the increased soil N mineralization, an increase in nitrate leaching is not to be expected (Cuttle & Scholefield, 1995). Furthermore, when slurry is applied at high rates or under suboptimal conditions, a reduced plant available N fraction of slurry with a high C:N$_{total}$ ratio might reduce the risk for N losses with both leaching and ammonia emission. Slurry composition might also affect the emission of N_2O following application to soil. Velthof *et al.*, (2003) formulated the hypothesis that animal manures with a relatively high content of mineralizable C result in higher N_2O emissions after soil application than animal manures with more resistant C. This would reduce the risk for N_2O losses after soil application with the low digestible diets promoted in the VEL and VANLA project. However, the impact of this is probably not large as the risk of N_2O emission following manure application on permanent grassland with a high OM content is relatively low (Velthof *et al.*, 2003).

7.3.4 Improved slurry quality?

One of the hypotheses in the VEL and VANLA project was that slurry with a higher $C:N_{total}$ ratio is of a better quality as it would have a positive impact on the soil food web. For instance, it was presumed that manure with a high $C:N_{total}$ ratio would contain less phytotoxic substances such as phenolic compounds and biogenic amines (Van Bruchem, 1999b). In Chapter 3 the content of these compounds in four slurries derived from different feeding strategies, but all with a relatively high $C:N_{total}$ ratio (between 8.9 and 15.5), appeared to be minimal. Differerences in phytotoxicity between the four slurries were shown in a cress germination test but it was concluded that these differences are not likely to be relevant in established grasslands as herbage yield was highest with the slurry with the highest phytotoxicity (Chapter 3). Therefore, this research path was discontinued.

The manure produced in the experiment described in Chapter 4 was used to test quality aspects in several experiments. Van der Stelt (2007) showed large increases in ammonia emission under laboratory conditions for the high protein slurries. Van Vliet *et al.* (submitted) showed that species diversity of bacteria in manure did not differ between high or low energy or protein diets, but dietary protein level did result in a shift in relative abundance of certain bacteria. Franz *et al.* (2005) showed that the rate of decline of E. coli O157:H7 was fastest decline in manure produced from the pure straw diet and slowest in manure from the diet of grass silage plus maize silage. Finally, Van den Pol-van Dasselaar *et al.* (2006) showed differences in soil food web structures between slurries obtained from farms with different feeding strategies in a pot experiment. Slurry with a large content of $N_{organic}$ appeared to increase the number of predacious nematodes, leading to a better developed soil food web, which in its turn may lead to a higher natural fertility of the soil.

An increase in soil organic matter content in the case of slurry with a high $C:N_{total}$ ratio (as was simulated in Chapter 4) might lead to positive effects on herbage productivity through beneficial effects on soil structure by improving aeration, infiltration and rootability. Brussaard *et al.* (2007) state that there is evidence that soil biota-mediated soil structure also affects the N use efficiency of plants. Regarding the large increase in the amount of residual soil N that is to be expected with increased slurry $C:N_{total}$ ratio's (Figure 7.2), a better understanding of the effect of differences in slurry composition on the functioning of soil food web warrants further investigation. However, all these effects will be related to the specific conditions of the actual manure application. The statement that slurry with a high C:N_{total} ratio is of a better quality is too simple.

7.4 On a further reduction of N surpluses from Dutch dairy farming

Through new technological models and especially the unrestricted and cheap access to external nutrients in the second phase of the modernization trajectory (1950–1990) and due to the strong institutionalization of agricultural sciences and extension, farming in this period was increasingly understood as the unfolding of generally applicable agricultural rules with farm performance being the logical outcome of technology and external inputs (Textbox 1.2). As a consequence, characteristics of farm internal resources and their interactions became of minor importance in farm management strategies. During the late 1980s and 1990s it became clear that the negative environmental impact of this type of agriculture had to be reduced. To obtain this reduction without losing productivity required an improvement of farm efficiency and a re-valuation of farm-specific resources. However, this did not match with the idea of the unfolding of generally applicable rules that has determined our view on farm management for a long time. Specific soils, specific crops, specific animals, specific weather conditions require specific strategies to avoid nutrient losses. Furthermore, all farmers have their own way of ordering the production process partly based on personal preferences and capabilities. To a certain extent improved nutrient management asks for a re-invention of the art-of-farming (Textbox 1.1, Van der Meulen, 1942).

In this process, the interaction between different disciplines and the fine-tuning of farm-specific resources becomes of major importance. The novelty that is central in my research emerged exactly at the junction of cow nutritition, plant nutrition and soil processes. At present, this area of research tends to represent a gap in scientific knowledge. This is, in my opinion, a logical consequence of the lack of integration of agricultural disciplines during the second phase of the modernization trajectory (Chapter 1). The need for an integrated whole-farm approach of nutrient management has been expressed by many authors (Aarts, 2000; Børsting *et al*., 2003; Lantinga *et al*., 2004; Rotz *et al*., 2005). On the other hand, it is recognized that nutrient management requires detailed scientific knowledge at the disciplinary level (e.g. Shepherd & Chambers, 2006). Integrated apporoaches will thus have to represent variation and interactions between the various sub-systems on the farm (Dijkstra *et al*., 2007a). Combining these two needs is one of the major challenges for future nutrient management research. A possible route to take this challenge is by producing mechanistic simulation models that are able to translate detailed disciplinary knowledge into useful information for other disciplines at the farm level. The modeling approach presented in Chapter 5 is an example of this.

Effective nutrient management strategies require an integrative view on the various subsystems of the farm. Cow feeding on a dairy farm is inextricably related to crop production, grassland management and manure practices. Effective strategies require that these different different disciplines are attuned. However, dairy cow feeding is often evaluated out of this farm context. When evaluating results of feeding experiments with low protein diets it is often concluded that these diets are not attractive as they result in a reduction of milk production. Whether the obtained production level might be optimal regarding an efficient utilization of home-grown feed is rarely taken into account. To assist farmers in formulating diet composition in an integrated manner, multiple objectives such as the reduction of nutrient excretion, manipulation of manure composition and utilization of homegrown forage should be incorporated in diet optimization techniques.

In the MINAS system, farmers had the opportunity to select the management strategies that fitted best within their specific situation. Oenema *et al*. (2006) state: “the introduction of MINAS has greatly contributed to the understanding of nutrient cycling and nutrient management at farm level, especially on dairy farms. Switching to a manure policy based on N and P application standards instead of balances is a step backwards in this respect.” For a further reduction of nutrient losses, it seems crucial to develop legislation that gives farmers the same flexibility and insight.

During the MINAS period dairy projects like VEL & VANLA, Farmers Data Project (Ondersteijn, 2002), Bioveem (Baars *et al*., 2002) and Cows & Opportunities (Oenema *et al*., 2001) have given a new impulse to knowledge exchange between science and farming practice. This trajectory has been recently extended by a large project on knowledge networks in Dutch animal farming (Wielinga *et al*., 2007). In my opinion, a further reduction of nutrient surpluses requires both a continuation and a deepening of this approach. To formulate consistent and effective nutrient management strategies, detailed knowledge and commitment of both scientists and farmers are needed.

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Summary

Intensification of Dutch dairy farming during the second phase of the modernisation trajectory (1950–1990) was based on the use of large amounts of external inputs, especially artificial fertilizer and concentrates. As a result, the N conversion efficiency (output/input) of the dairy sector as a whole decreased from 46% in the 1950s to only 16% in the mid 1980s. From the early 1980s onwards the negative environmental consequences of this low N efficiency became recognised and since this time a gradual tightening of environmental policies has been implemented. This has resulted in a considerable reduction of the N surpluses of dairy farms during the last ten years. It has been shown that improved management can strongly contribute to the reduction of N surpluses without having negative effects on the productivity of farms. However, to comply with future environmental goals laid down in multiple international agreements a further improvement of this management seems required.

The large increase of N surpluses in the second half of the 20th century coincided with a strong institutionalisation of agricultural sciences and extension. Through new technological models and the unrestricted and cheap access to external nutrients in this period, farming was increasingly understood as the unfolding of generally applicable agricultural rules with farm performance being the logical outcome of technology and external inputs. As a consequence, characteristics of farm internal resources and their interactions became of minor importance in farm management. Improved nutrient management, however, requires specific solutions, an integrated perspective on various agronomical disciplines and a re-valuation of farm-internal resources such as the soil, the feed and the manure. The desired changes in management might therefore require a certain break with the existing regime and its routines.

A novelty is a configuration that is observed in practice and contains the promise of a shift in established patterns. This thesis deals with such a novelty: that is the idea that the composition of slurry can be modified on dairy farms by means of diet adjustments and that this modification contributes to reduced N losses from grassland-based dairy farms. This deliberate adaptation (by the farmers regarded as an improvement) of cow slurry is one of the crucial elements of a management strategy, applied and promoted by several groups of dairy farmers in the Netherlands during the last decade. This strategy is characterised by a set of interrelated changes in grassland management and feeding. Its basic idea is to adjust diet and grass silage composition towards lower protein and higher fibre contents by reducing the fertilizer N input and postponing the cutting moment. It is anticipated that the proposed adjustments in diet and manure will result in slurry that is less susceptible to losses of N to the environment, through an increase of the $C:N_{total}$ ratio of slurry and a decrease of the $N_{inorganic} : N_{total}$ ratio.

A large part of this research has been executed in the northern Friesian Woodlands within the context of the nutrient management project of VEL & VANLA. This project ran from 1998 to 2003 and had the aim to find cost-effective strategies for the reduction of N surpluses, appropriate to the local situation. For various reasons the production of maize silage was not attractive to most of these farmers. Besides the implementation of the described novelty, the project was characterized by the creation of a joint learning process, stimulating the farmers to actively discuss the implemented management changes. The major part of the 60 participating farmers, succeeded in reducing the farm level N surpluses, mainly through a reduction of fertiliser input. It was shown that this reduction was on average reflected in reduced N levels in the diet, roughage and manure without adverse effects on farm productivity.

The potential variation in slurry composition as affected by diet composition was explored in an experiment with non-lactating cows under controlled conditions, through model simulations and through the monitoring of 12 farms in the VEL & VANLA project. It was concluded that both $C:N_{total}$ ratio and $N_{inorganic} : N_{total}$ ratio can be manipulated by dietary changes. The $C:N_{total}$ ratio of dairy cow slurry will typically range between 6 and 12. Obtaining high $C:N_{total}$ ratio's in the slurry requires both a low N excretion as a result of low protein contents and a high OM or C excretion as a result of a low overall diet digestibility. This can be attained by various strategies such as the use of low digestible grass silages as proposed in the VEL and VANLA project but also by the inclusion maize silage, cereal silages or straw in the diet.

The VEL and VANLA farmers succeeded in the aim to reduce the $N_{inorganic} : N_{total}$ ratio of the slurry. Reduced $N_{inorganic} : N_{total}$ ratio's in the slurry were significantly associated with a reduced digestibility and protein content of grass silage, showing that the typical feeding strategy proposed in the project played a crucial role in the reduction of this ratio. Besides a reduction of the urinary N relative to the faecal N output, also a reduced mineralization rate of faecal N in the slurry storage with low energy diets has probably played a role in this. In general terms, it has been shown that the reduction of excessive protein feeding results in increased $C:N_{total}$ ratio's and decreased $N_{inorganic}$ concentrations in slurry. However, it was also demonstrated that the effect of dietary changes on excreta composition is detailed and complex. The modelling approach presented in Chapter 5 takes this complexity into account and further development and testing of this model can result in a powerful instrument to evaluate the consequences of changes in diet composition on the composition of manure.

The mineral fertilizer equivalent (MFE) of 12 dairy slurries with a variable composition ($C:N_{total}$ ratio ranged from 5.1–11.4) was evaluated in a one-year grassland experiment by slit-injecting them into two grassland fields on the same sandy soil series in the Friesian Woodlands. Eight slurries were derived from an experiment in which non-lactating dairy cows were fed diets with extreme high and low levels of dietary protein and energy. The other four were derived from dairy farms with different feeding and slurry management. On both fields, the MFE appeared to be positively related to the ammonium content and negatively to the C:N$_{total}$ ratio of the slurry. In the current situation with an allowed ceiling dosage of 250 kg N ha^{-1} yr^{-1}, the observed differences imply that an increase of the C:N$_{total}$ ratio from 6 to 12 will result in a reduction of the amount of plant available N of approximately 35 kg N ha^{-1} yr^{-1} and a reduction of the N losses with ammonia of approximately 25 kg N ha^{-1} yr^{-1}, resulting in an increase of 60 kg residual soil N ha^{-1} yr^{-1}. Model simulations revealed that the reduced first-year N availability of slurry with a high C:N$_{total}$ ratio as observed in the grassland experiment will eventually be compensated for by increased soil N mineralization but only on the very long term.

One of the hypotheses in the project was that slurry with a higher C:N$_{total}$ ratio would have a positive impact on the soil food web. For instance, it was presumed that slurry with a high C:N$_{total}$ ratio would contain less phytotoxic substances. Differerences in phytotoxicity between four slurries derived from farms with different feeding strategies were shown in a cress germination test but it was concluded that these differences are not likely to be relevant in established grasslands as herbage yield was highest with the slurry with the highest phytotoxicity. Model simulations did reveal an increase in soil organic matter content in the case of slurry with a high C:N$_{total}$ ratio which might lead to beneficial effects on soil structure by improving aeration, infiltration and rootability which may affect the N use efficiency of plants. In an accompanying research, differences in soil food web structures between slurries obtained from farms with different feeding strategies were observed in a pot experiment. Regarding the large increase in the amount of residual soil N that is to be expected with increased slurry C:N$_{total}$ ratio's, a better understanding of the effect of differences in slurry composition on the functioning of soil food web warrants further investigation.

Monitoring of winter diet composition and herd performance on twelve of the VEL and VANLA farms a few years after the introduction of the strategy revealed that the typical reduction of both the net energy (VEM) and crude protein (CP) level of the grass silages was widely adopted by these farmers. Excessive protein feeding was substantially reduced but the data showed still a large potential for a further reduction of N excretion per kg milk produced. From this empirical dataset a theoretical lower boundary of 11.4 g N kg^{-1} FPCM was derived. In the current situation, such a performance could increase the potential milk production (per ha) of individual farms by more than 20% compared to the average. Variation in N excretion was observed irrespective of the level of milk production per cow which implies that farmers are not necessarily restricted to a certain level of milk production to reduce N excretion.

On average, the diet adjustments proposed by the project were associated with a slightly lower milk production per cow but reduced N excretions and higher economic margins per kg milk produced. Thus, for farms with predominantly grassland aiming at a moderate production level, the proposed strategy can be an effective instrument to reduce N excretion. However, the success in terms of economic and environmental performance was variable. On farms with increased feed costs in the course of the project, characterized by high dietary energy contents in the initial situation, also the environmental performance was not improved as the limited reduction in total N intake coincided with a similar reduction in milk protein production. On these farms, other strategies to reduce N excretion such as the use of maize or cereal silages or low protein concentrate feeds in combination with high digestible grass silages might have given a better performance. It is concluded that feeding strategies to reduce N excretion should always focus on a decrease of the protein to energy ratio, especially that of the homegrown forage but the definition of the strategy should be individually differentiated and integrated in whole-farm nutrient management plans. To assist farmers in formulating diet composition in an integrated manner, multiple objectives such as the reduction of nutrient excretion, manipulation of manure composition and utilization of homegrown forage should be incorporated in diet optimization techniques.

A further reduction of N losses from dairy farms should focus on assisting farmers in developing diverse but consistent strategies that apply to the farm-specific situation. Main challenge seems to translate the detailed disciplinary knowledge that is required into useful information at farm level. Furthermore, the chosen trajectory of co-operation between scientists and farmers needs to be prolonged and deepened. Not only the knowledge but also the commitment of both groups will be needed.

Samenvatting

In de tweede fase van het moderniseringstraject (1950–1990) was er sprake van een sterke intensivering van de Nederlandse melkveehouderij. Deze intensivering was onder andere gebaseerd op een sterke toename van het gebruik van kunstmest en krachtvoer. Ten gevolge hiervan daalde de stikstof (N) efficiëntie (output/input) van de gehele Nederlandse melkveehouderij van 46% in 1950 tot slechts 16% in 1985. Vanaf die tijd is er in Nederland sprake van een geleidelijk aan steeds strenger wordende mest- en milieuwetgeving. Gedurende de laatste tien jaren is het N overschot van Nederlandse melkveebedrijven aanzienlijk gedaald. Gebleken is dat dit niet ten koste ging van de productiviteit van de sector, zodat de N efficiëntie toenam. Echter, om te voldoen aan toekomstige milieudoelstellingen die zijn vastgelegd in meerdere internationale verdragen, is een verdere verlaging van N verliezen noodzakelijk.

De sterke verhoging van N overschotten in de tweede helft van de 20ste eeuw ging gepaard met een sterke institutionalisering van de landbouwwetenschappen en voorlichting. Met nieuwe technologische modellen en een nagenoeg onbegrensde en goedkope toegang tot externe inputs in deze periode werd de landbouwkundige bedrijfsvoering in toenemende mate begrepen als de ontvouwing van algemeen geldende wetten waarin de prestaties van een bedrijf het logische gevolg waren van de gebruikte technologieën en inputs. Als gevolg hiervan werden eigenschappen van bedrijfseigen productiemiddelen en hun samenhang van ondergeschikt belang in de bedrijfsvoering. Een verbetering van mineralenmanagement vraagt echter specifieke oplossingen, een geïntegreerd perspectief op verschillende landbouwkundige disciplines en herwaardering van bedrijfseigen hulpmiddelen zoals bodem, voer en mest. De benodigde veranderingen in bedrijfsvoering vragen daarom mogelijk om een bepaalde breuk met bestaande regimes en routines.

Een *novelty* is een fenomeen dat in de praktijk wordt waargenomen en de belofte omvat om een verandering te bewerkstelligen in gevestigde patronen. Dit proefschrift gaat over zo'n *novelty*, namelijk het idee dat de samenstelling van drijfmest op melkveebedrijven kan worden aangepast door middel van voedingsmaatregelen en dat deze aanpassing leidt tot een vermindering van N verliezen van melkveebedrijven op grasland. Deze bewuste aanpassing (door de betreffende ondernemers beschouwd als verbetering) van rundveedrijfmest is één van de cruciale aspecten van een managementstrategie die door verschillende groepen melkveehouders is toegepast en gepromoot gedurende het laatste decennium. Deze strategie bestaat uit een samenhangende set van managementmaatregelen op het gebied van veevoeding en graslandbeheer. Uitgangspunt van deze strategie is het voeren van eiwitarme en vezelrijke rantsoenen en graskuilen door middel van een verlaging van de N gift op grasland en het uitstellen van het maaitijdstip. De verwachting bij deze strategie is dat de aanpassingen in het rantsoen leiden tot een type drijfmest dat minder vatbaar is voor

N verliezen naar het milieu door enerzijds een verhoging van de $C:N_{totaal}$ verhouding en anderzijds een verlaging van de $N_{mineraal} : N_{totaal}$ verhouding.

Een groot gedeelte van het in dit proefschrift beschreven onderzoek is uitgevoerd in het kader van het mineralenmanagement project van de milieu-coöperaties VEL en VANLA in de Noordelijke Friese Wouden. Dit project liep van 1998 tot 2003 en had als doel kosteneffectieve en lokaal toepasbare strategieën te ontwikkelen ter verlaging van N overschotten. Om verschillende redenen was het verbouwen van snijmaïs niet aantrekkelijk voor deze melkveehouders. Behalve door de beschreven *novelty*, werd het VEL en VANLA project gekenmerkt door het creëren van een gezamenlijk leerproces waarin de melkveehouders werden gestimuleerd de voorgestelde maatregelen te bediscussiëren en te introduceren op hun bedrijf. Het merendeel van de 60 deelnemende bedrijven slaagde erin het N overschot op bedrijfsniveau aanzienlijk te verlagen, voornamelijk door een verlaging van het kunstmestgebruik. Deze verlaging resulteerde in gemiddeld lagere N gehaltes in ruwvoer, rantsoenen en mest zonder negatieve gevolgen voor de productiviteit op bedrijfsniveau.

De mogelijke variatie in drijfmestsamenstelling als gevolg van verschillen in rantsoensamenstelling werd onderzocht (i) in een experiment met niet-melkgevende koeien onder gecontroleerde omstandigheden, (ii) door middel van modelsimulaties, en (iii) door het monitoren van 12 bedrijven in het VEL & VANLA project. Geconcludeerd werd dat zowel de $C:N_{totaal}$ ratio als de $N_{mineraal} : N_{totaal}$ verhouding aanzienlijk kunnen worden beïnvloed door rantsoenaanpassingen. The $C:N_{totaal}$ verhouding van drijfmest op melkveebedrijven varieerde tussen 6 en 12. Het verkrijgen van een hoge $C:N_{totaal}$ verhouding vereist zowel een lage N excretie als gevolg van lage eiwitoverschotten in het rantsoen als een hoge organische stof of C excretie als gevolg van een lage verteerbaarheid. Dit kan met behulp van meerdere strategieën worden bereikt waaronder het gebruik van vezelrijke en eiwitarme graskuilen zoals in het VEL & VANLA project werd nagestreefd, maar ook door een groter aandeel snijmaïs, graansilage of stro in het rantsoen. De VEL & VANLA boeren slaagden in hun opzet om de $N_{mineraal} : N_{totaal}$ verhouding van de drijfmest te verlagen. De $N_{mineraal} : N_{totaal}$ verhouding in de drijfmest was positief gecorreleerd met het eiwitgehalte en de verteerbaarheid van de gevoerde graskuil. Dit toont aan dat de typische strategie van het VEL & VANLA project een cruciale rol heeft gespeeld in de verlaging van deze verhouding. Behalve een verlaging van de verhouding tussen urine N en mest N heeft waarschijnlijk ook een verlaagde mineralisatie van fecale N in de mestopslag hiertoe bijgedragen. De verschillende hoofdstukken in dit proefschrift laten zien dat in zijn algemeenheid de verlaging van overmatige eiwitvoeding resulteert in een hogere $C:N_{totaal}$ verhouding en lagere gehaltes aan minerale N in drijfmest. Dit proefschrift laat echter ook zien dat het effect van rantsoensamenstelling op de samenstelling van mest en urine complex is. De gevolgde modelmatige benadering in hoofdstuk 5 houdt rekening met deze complexiteit, en verdere ontwikkeling van dit model kan resulteren in een krachtig instrument dat melkveehouders kan ondersteunen bij de evaluatie van het effect van rantsoensamenstelling op de samenstelling van de mest.

De N werkingscoëfficiënt bij zodebemesten van 12 drijfmesten van variabele samenstelling ($C:N_{totaal}$ verhouding variërend tussen 5.1 en 11.4) werd getest in een 1-jarig experiment op twee graslandpercelen op een zandgrond in de Noordelijke Friese Wouden. Acht van de drijfmesten waren afkomstig van een experiment waar niet-melkgevende koeien werden gevoerd met rantsoenen gekenmerkt door extreem hoge en lage gehaltes aan eiwit en energie in verschillende combinaties. De andere vier drijfmesten werden verzameld op praktijkbedrijven met uiteenlopend voer- en mestmanagement. Op beide percelen bleek de N werkingscoëfficiënt positief gerelateerd aan de $N_{mineraal} : N_{totaal}$ verhouding in de drijfmest en negatief aan de $C:N_{totaal}$ verhouding. Een voorbeeldberekening gebaseerd op de huidige maximaal toegestane dierlijke mestgift in Nederland van 250 kg N ha^{-1} jr^{-1} laat zien dat verhoging van de $C:N_{totaal}$ verhouding in drijfmest van 6 naar 12 zal resulteren in een verlaging van de hoeveelheid plant-beschikbare N met ongeveer 35 kg N ha^{-1} jr^{-1} en een verlaging van de ammoniak N verliezen met ongeveer 25 kg N ha^{-1} jr^{-1}. Dit ten faveure van een verhoging van de hoeveelheid N die in de bodem wordt vastgelegd (60 kg N ha^{-1} jr^{-1}). Modelsimulaties lieten zien dat de lagere fractie plant-beschikbare N pas na decennia zal worden gecompenseerd door een hogere mineralisatie van bodem N.

Eén van de hypotheses in het VEL & VANLA project was dat drijfmest met een hogere $C:N_{totaal}$ verhouding een positieve invloed zou hebben op het bodemvoedselweb. Het werd bijvoorbeeld verondersteld dat drijfmest met een hoge $C:N_{totaal}$ verhouding minder phytotoxische componenten zou bevatten. Verschillen in phytotoxiciteit tussen vier drijfmestsoorten verzameld op bedrijven met verschillende voerstrategieën werden aangetoond in een kiemproef met tuinkers, maar omdat de drijfmest met de hoogste phytotoxiciteit tegelijkertijd de hoogste opbrengst gaf in een bemestingsexperiment werd geconcludeerd dat deze verschillen waarschijnlijk niet relevant zullen zijn in een gevestigde graslandzode. Modelsimulaties lieten een verhoging zien van het gehalte aan organische stof in de bodem bij gebruik van drijfmest met een hoge $C:N_{totaal}$ verhouding. Dit zou kunnen leiden tot positieve effecten op de bodemstructuur als gevolg van een betere beluchting, infiltratie en beworteling. In theorie kan hierdoor de N-opname door de graszode gestimuleerd worden. In een aanverwant potexperiment werden inderdaad verschillen aangetoond in de samenstelling van het bodemvoedselweb tussen drijfmesten afkomstig van bedrijven met verschillende voerstrategieën. Gezien de verhoging van de hoeveelheid bodem N die verwacht mag worden bij een verhoogde $C:N_{totaal}$ verhouding in drijfmest, is nader onderzoek naar de effecten van drijfmestsamenstelling op het functioneren van het bodemvoedselweb wenselijk.

Monitoring van winterrantsoenen op twaalf VEL & VANLA bedrijven een aantal jaren na aanvang van het project liet zien dat het verlagen van het energie (VEM) en eiwitgehalte van de graskuilen in belangrijke mate was doorgevoerd op deze bedrijven.

Gemiddeld heeft dit geleid tot een substantiële verlaging van de eiwitoverschotten in de rantsoenen, maar de gegevens laten zien dat er nog een aanzienlijk potentieel bestaat voor verdere verlaging van de N excretie per kg geproduceerde melk. Uit de empirische dataset werd een theoretische ondergrens van 11.4 g N kg^{-1} meetmelk afgeleid. In de huidige situatie zou een dergelijke prestatie de potentiële melkproductie per ha op individuele bedrijven met meer dan 20% kunnen verhogen ten opzichte van het gemiddelde omdat het een hogere veebezetting mogelijk maakt. De variatie in N uitscheiding per kg meetmelk bleek sterk variabel binnen gegeven productieniveaus. Dit betekent dat veehouders niet noodzakelijkerwijs gebonden zijn aan een bepaald productieniveau om een lagere N excretie na te streven.

Het rantsoentype dat in het VEL & VANLA project werd gepromoot ging gemiddeld gepaard met een iets lagere melkproductie per koe, maar ook met een lagere N excretie én hogere marges tussen melkopbrengsten en voerkosten per kg melk. De voorgestelde strategie kan daarmee als een effectief instrument worden beschouwd ter verlaging van de N excretie en ammoniakverliezen op melkveebedrijven met overwegend grasland welke zich richten op een gematigd productieniveau per koe. Het succes van de strategie in economisch en milieukundig opzicht was echter behoorlijk variabel. Daar waar bedrijven met dalende of stabiliserende voerkosten een duidelijke verlaging van de N excretie realiseerden, daalde de N excretie op bedrijven met verhoogde voerkosten in de loop van het project nauwelijks doordat een kleine afname van de voer-N opname gepaard ging met een vergelijkbare verlaging van de melkeiwitproductie. Deze laatste bedrijven werden gekarakteriseerd door hoge energiegehaltes in het rantsoen bij aanvang van het project. Andere strategieën zoals het gebruik van maissilage, graansilages of krachtvoeders met een lager eiwitgehalte hadden mogelijk een beter resultaat gegeven op deze bedrijven. Geconcludeerd werd dat voerstrategieën ter verlaging van de N excretie altijd gericht moeten zijn op een verlaging van de eiwit : energie verhouding van het voer, vooral die van het eigen ruwvoer, maar dat de definitie van voerstrategieën per bedrijf afzonderlijk moet worden gedifferentieerd. Tevens zouden doelstellingen als reductie van excretie en aanpassing van mestsamenstelling moeten worden meegenomen bij de optimalisatie van rantsoenen. Hierdoor wordt de veevoeding een beter geïntegreerd onderdeel van mineralenmanagement op bedrijfsniveau.

Een verdere verlaging van N verliezen op melkveebedrijven zou zich moet richten op het bijstaan van melkveehouders bij de ontwikkeling van diverse, maar consistente strategieën die betrekking hebben op de bedrijfsspecifieke situatie. Belangrijkste uitdaging hierbij is om de gedetailleerde disciplinaire kennis die hiervoor nodig is te vertalen in nuttige informatie op bedrijfsniveau. Daarnaast zal de ingeslagen weg van samenwerking tussen wetenschap en praktijk moet worden voortgezet en verdiept. Niet alleen de kennis maar ook volledige betrokkenheid van beide groepen is hierbij onontbeerlijk.

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Curriculum Vitae

Johannes Wilhelmus (Joan) Reijs werd op 30 oktober 1975 geboren in Oss en is opgegroeid op het ouderlijke melkveebedrijf in Keent (Noord-Brabant). Na het behalen van het VWO-diploma aan het Titus Brandsma Lyceum in Oss begon hij in 1994 met de studie Zoötechniek aan de toenmalige Landbouwuniversiteit in Wageningen. Zijn afstudeeronderzoeken richtten zich op opfokmanagement op Nederlandse melkveebedrijven (Agrarische Bedrijfseconomie, 1999) en het modelleren van nutriëntbeschikbaarheid op uiteenlopende melkveerantsoenen (Diervoeding, 2000). Na zijn afstuderen, trad hij in februari 2000 als assistent in opleiding in dienst bij het departement Dierwetenschappen in Wageningen. In 2005 en 2006 werkte hij enkele maanden als toegevoegd onderzoeker bij de leerstoelgroep Rurale Sociologie. Vanaf september 2006 is hij in dienst van het Landbouw Economisch Instituut in Den Haag waar hij zich richt op de relatie tussen beleid, bedrijfsvoering en milieubelasting op Nederlandse landbouwbedrijven. Daarnaast is hij vanaf 1996 actief als melkveehouder in een maatschapsverband in Bergharen (Gelderland).

Johannes Wilhelmus (Joan) Reijs was born on 30 oktober 1975 in Oss and has grown up on the parental dairy farm in Keent (Noord-Brabant). After his graduation from the Titus Brandsma Lyceum in Oss he started the study Animal Sciences at the former Agricultural University in Wageningen in 1994. His theses dealt with heifer management on Dutch dairy farms (Farm Economics, 1999) and the modelling of nutrient availability on various dairy cow diets (Animal Nutrition, 2000). After his graduation, he started in February 2000 with a PhD project at the Department of Animal Sciences of Wageningen University. In 2005 and 2006 he has been working a few months as a temporarily researcher of the Rural Sociology group in Wageningen. Since September 2006 he is employed at the Agricultural Economics Research Institute in The Hague where he is dealing with the relation between policies, farm management and environmental performance of agricultural enterprises in the Netherlands. Furthermore, from 1996 onwards, he is active as a dairy farmer in partnership in Bergharen (Gelderland).

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